Ocular Anatomy

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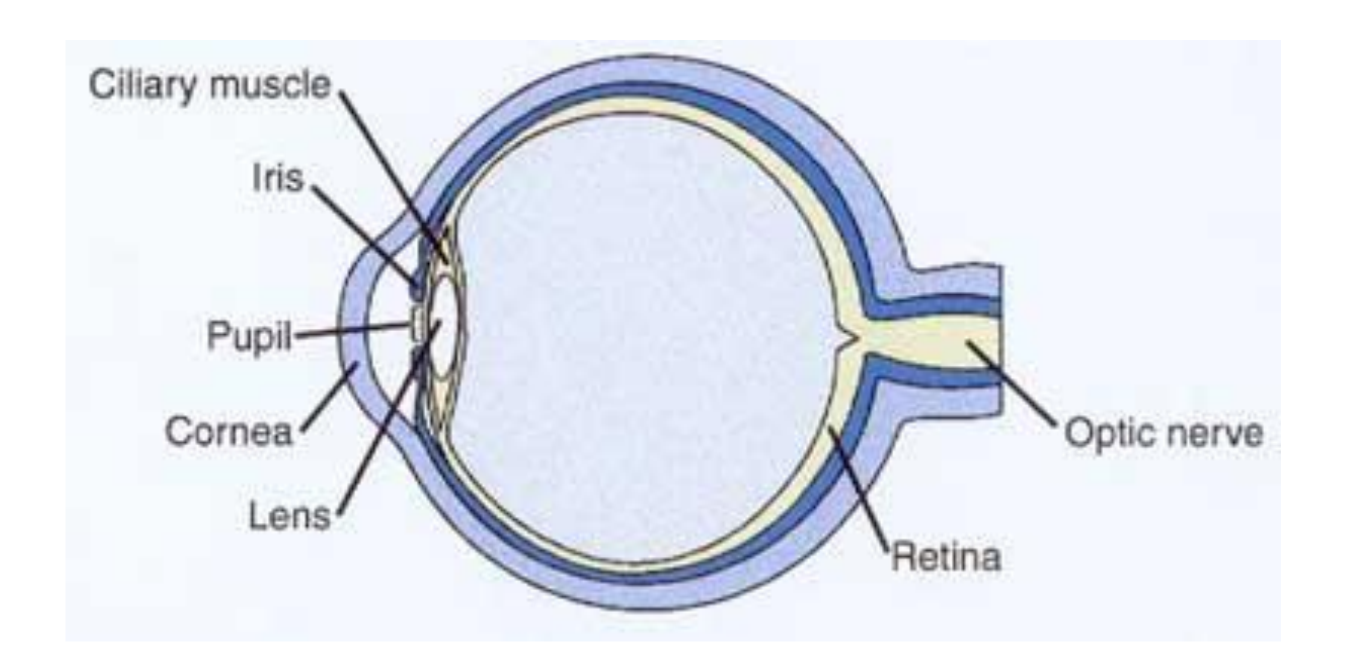
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جراحة العيون



Nisreen Al-Aqqad

الإهداء

إلى رمز الحب و العطاء...........................والدي الكرام

إلى رفيق دربي......................................زوجي العزيز

و إلى جميع من وقف بجانبي لإتمام هذا العمل

نسرين العقاد

Contents

Introduction

This book provides optometry students with the basic knowledge of the ocular anatomy for clinical practice.

It includes microscopic anatomy of the eyeball, ocular appendages, nerves and blood supply for each structure, and the visual pathway.

Chapter one

The Orbital Cavity

The Orbital Cavity

- The orbital cavity:

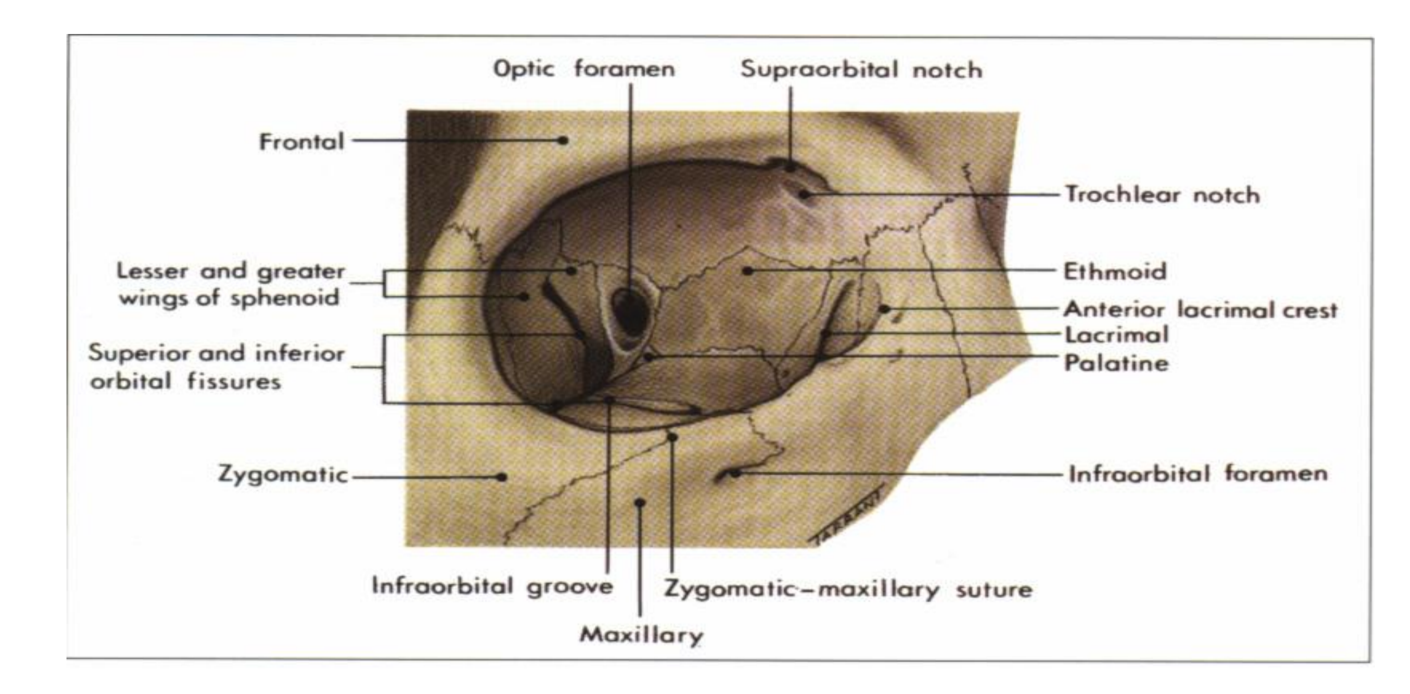
Are pair of large bony sockets that contain the eyeballs, their associated muscles, nerves, vessels, fat, and most of the lacrimal apparatus.

- The orbital margin is quadrilaterateral with rounded corners, the depth of the orbit is approximately 40 mm, the height is 35 mm and the width is 40 mm.

- Seven individual bones form the orbit :

- The maxilla and palatine, the zygomatic and sphenoid, the Frontal, the ethmoid, and the lacrimal bones.

- The walls of the orbital cavity consist of a roof, a floor, and a medial and lateral wall.



❖ The roof consists of:

1. Orbital plate of frontal bone.
2. Lesser wing of sphenoid.

❖ The floor consists of:

1. Orbital plate of maxillary bone.
2. Orbital surface of zygomatic bone.
3. Small orbital process of the palatine bone.

❖ The lateral wall consists of:

1. Zygomatic bone.
2. Greater wing of sphenoid bone.

- Note: the lateral wall is the thickest wall.

❖ The medial wall consists of :

1. Small part of sphenoid.
2. Frontal process of maxilla.
3. Lacrimal bone.
4. Orbital plate of ethmoid bone.

➢ Openings into the orbital cavity:

1. The optic canal which lies in the lesser wing of sphenoid.

- The optic canal transmits the optic nerve and the ophthalmic artery with its surrounding sympathetic plexus.

2. Superior orbital fissure:

The lateral rectus muscle divides the superior orbital fissure to three divisions:

I. Above the muscle which contains:
- Lacrimal, frontal, and trochlear nerves.

- Superior ophthalmic vein.

II. Within the muscle which consists of:

- Nasocilliary nerve.
- Upper and lower divisions of oculomotor nerve.
- Abducent nerve.

III. Under the muscle :

- Inferior Ophthalmic vein.

3- Inferior orbital fissure:

It transmits the maxillary nerve, which immediately changes its name to infraorbital nerve; it also permits passage of the zygomatic nerve, branches of pterygopalatine ganglion,

4- The ethmoidal foramina:

-They are situated where the roof joins the medial wall.

- The anterior ethmoidal foramen transmits the anterior ethmoidal artery and nerve.

- The posterior ethmoidal foramen transmits the posterior ethmoidal nerve and artery.

5- Zygomaticofacial and zygomaticotemporal foramina:

- They are small foramina that lie on the lateral wall of the orbit.

-They transmit the Zygomaticofacial and zygomaticotemporal nerves

- Effect of age on the orbital cavity:

- At birth the orbital cavities are relatively large and the orbital margins are ossified and strong to protect the eyeball.

- In the young child the orbital cavities look more laterally than do those in an adult.

- In the child the distances between the orbits are small and they move apart later with the development.

- In old age, bony absorption occurs and this may result in holes appearing in the roof, lateral wall, and medial wall.

- Sex differences in the orbital cavities:

The bones of female orbits are smoother than in the male.

Chapter two

The Paranasal Sinuses

The Paranasal Sinuses

Paranasal sinuses:

Are cavities in the interior of the maxilla, frontal, sphenoid and ethmoid bones. They are filled with air and communicate with the nasal cavity through small apertures.

They vary in size and shape in different individuals and at different ages.

The function of these sinuses is:

1- To act as resonators to the voice.
2- To reduce the weight of the skull.

When the apertures of the sinuses are blocked or there is any inflammation, these sinuses will be filled with fluid and that more occurred in the frontal sinus and its symptoms are:

- ❖ Swelling in the upper and nasal side of the orbit.
- ❖ Exophthalmus.
- ❖ Swelling in the upper eyelid.
- ❖ Headache.

- The Sinuses are:

1- The maxillary sinuses:

The paired maxillary sinuses are the largest of Paranasal sinuses; they are located in the bodies of maxillae. They are pyramid-shaped.

- Nerve supply:

Infraorbital nerve and anterior, middle, and posterior superior alveolar nerves.

- Blood supply:

Anterior and posterior alveolar branches of the infraorbital and maxillary arteries, respectively.

The veins drain through the ostium and join the venous plexus in the nose.

- Lymphatic drainage:

Submandibular nodes.

2- Frontal sinuses:

The two frontal sinuses lie within the frontal bone; they are separated by bony septum. Each sinus is triangular in shape.

- Nerve supply:

Supraorbital nerve.

- Blood supply:

Supraorbital and anterior ethmoidal arteries.
The veins drain into the venous plexuses of the nose and into the supraorbital vein.

- Lymphatic drainage:

Submandibular nodes.

3- Sphenoidal sinuses:

The two sphenoidal sinuses lie within the body of sphenoid bone, they varies in their extent and development and may extent to reach the optic canal that surround the optic nerve.

This point is very important and the doctor must be very cautious during the surgery of these sinuses because any mistake may lead to optic nerve lesion and so the patient will become blind.

- Nerve supply:

Posterior ethmoidal nerve and the orbital branches of pterygopalatine ganglion.

- Blood supply:

Posterior ethmoidal arteries, the veins drain into the posterior ethmoidal veins.

- Lymphatic drainage:

The lymphatic vessels drain into the retropharyngeal nodes.

4- Ethmoidal sinuses:

They consist of a honeycomb of air cells that lie within the ethmoid bone between the nose and the orbit (medially).

The ethmoidal sinuses are grouped together as anterior, middle, and posterior.

- Nerve supply:

Anterior and posterior ethmoidal nerves and the orbital branches of pterygopalatine ganglion.

- Blood supply:

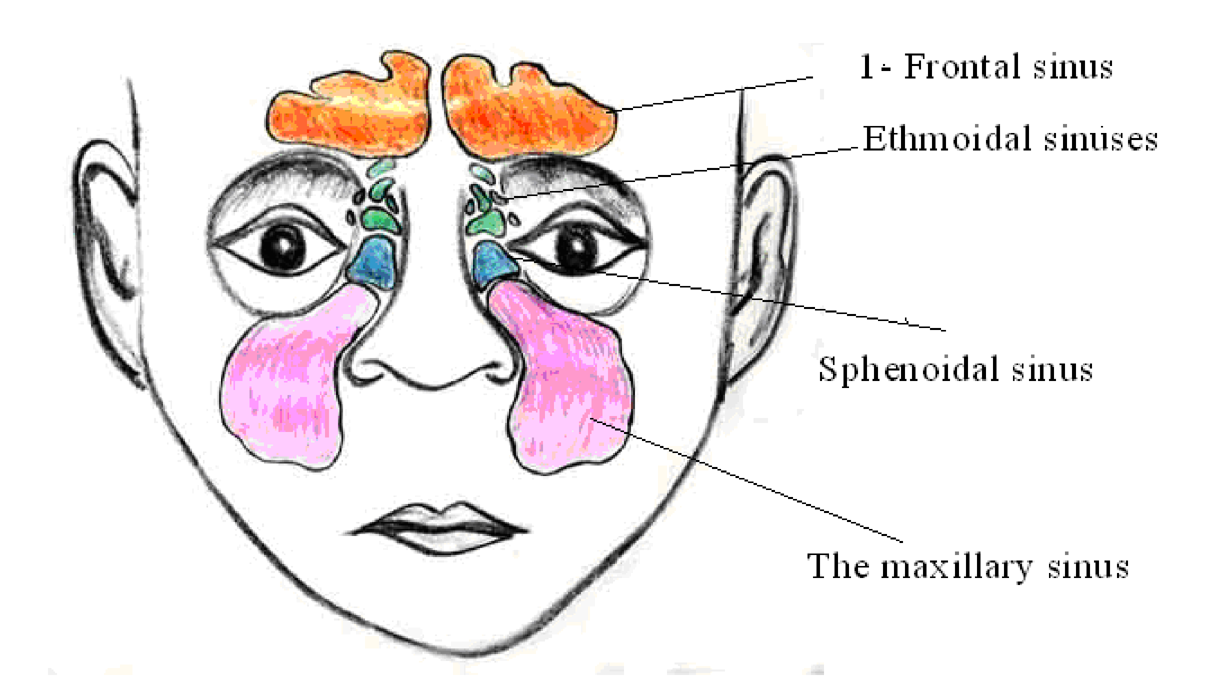
The arterial supply is from anterior and posterior ethmoidal arteries and the sphenopalatine artery.

The veins correspond to the arteries.

- Lymphatic drainage:

The anterior and middle group drains into the Submandibular nodes.

The posterior group drains into the retropharyngeal nodes.


1- Frontal sinus
Ethmoidal sinuses
Sphenoidal sinus
The maxillary sinus

Chapter Three

The Ocular Appendages

The Eyebrows

The eyebrows lie at the junction of the forehead and the upper lid.

Several muscles of facial expressions are inserted into the skin permitting movement of the eyebrows.

- Raising the eyebrows is accomplished by contracting the frontalis muscle; lowering the eyebrows by contracting the orbital part of orbicularis oculi muscle; drawing the eyebrows medially by contracting the corrugator supercilli muscle.

All these muscles are supplied by the seventh cranial nerve (facial nerve).

The eyebrows receive an arterial supply from the supraorbital and supratrochlear branches of the ophthalmic artery.

The corresponding veins drain into the angular vein and so enter the facial vein.

The lymphatic drainage of the lateral end is into the superficial parotid nodes and from the medial end into the submandibular nodes.

The Eyelids

An eyelid is a thin, movable fold of skin and muscle that covers and protects the eye.

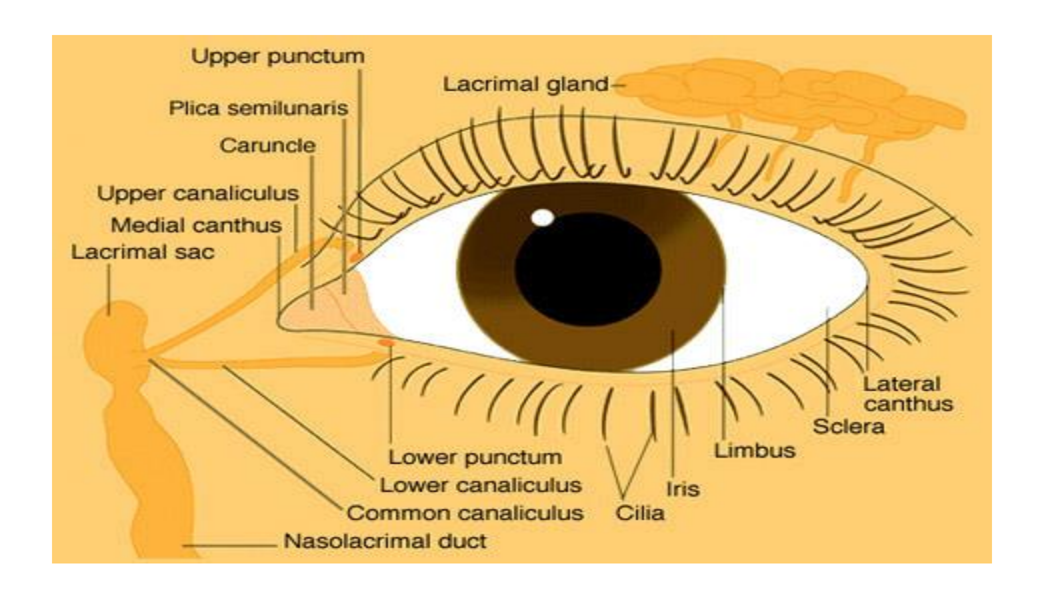
The upper eyelid is larger and more mobile than the lower.

The eyelids meet at the medial and lateral angles (or canthi).

The palpebral fissure is the elliptical opening between the two eyelids.

When the eye is closed, the upper eyelid completely covers the cornea, but when it is open the upper lid just covers the upper margin of the cornea and the lower lid lies below the cornea.

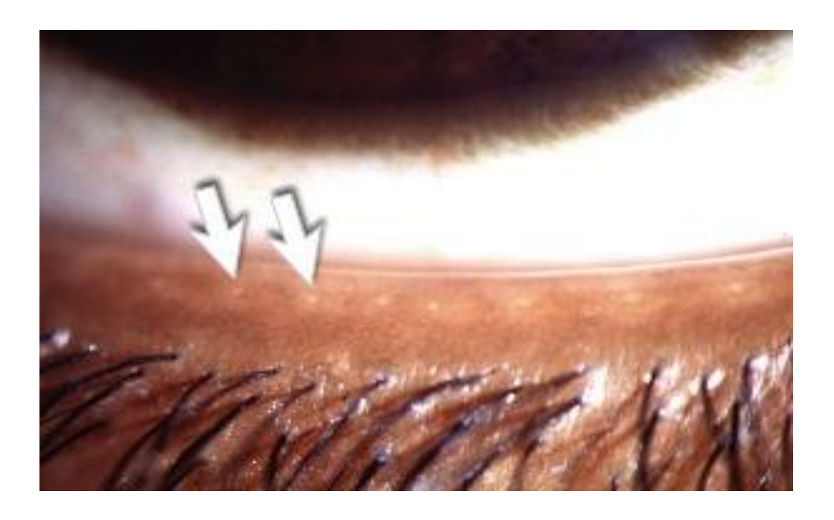
The lateral angle of the eye is directly in contact with the eyeball, whereas the medial rounded angle lies about 6mm medially from the eyeball. Here the two eyelids are separated by a small triangular space, the lacus lacrimalus, in the center of which is a small, pinkish elevation, the caruncula lacrimalus, a semi lunar fold, called the plica semilunaris, lies on the lateral side of the caruncle.



About 5 mm from the medial angle there is a small elevation, the papilla lacrimalus. On the summit of the papilla is a small hole, the punctum lacrimale, the puncta are turned towards the surface of the eye to receive the tear fluid,

Eyelashes grow in the palpebral margin, their distribution extending from the lateral canthus to the lacrimal papillae. They are short, thick and curved hairs, the upper lashes are thicker and more numerous than the lower one.

A grayish line or slight sulcus can sometimes be seen running along the eyelid margin between the eyelashes and the openings of the tarsal glands (meibomian glands), this represents the line between the anterior portion of the eyelid formed by the skin and orbicularis oculi muscle and the posterior portion formed by the tarsus and the conjunctiva.



In this figure the arrows point to the orifices of the tarsal glands (meibomian glands)

❖ Structure of the eyelid:

From superficial to deep, each eyelid consists of:
1) Skin
2) Subcutaneous tissue
3) Striated muscle fibers of the orbicularis oculi
4) Orbital septum and tarsal plate
5) Smooth muscle
6) Conjunctiva.

The upper lid also contains the aponeurosis of the levator palpebrae superioris muscle.

1- **The skin:**

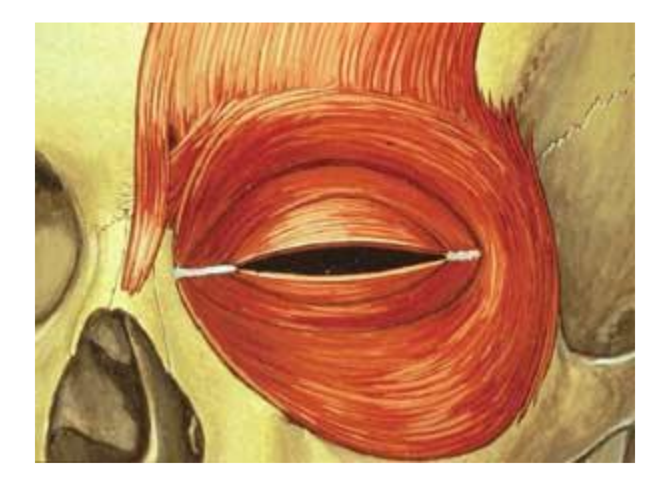
It is very thin and easily folds.
Microscopic examination of the skin shows many small hairs with sebaceous glands and small sweat glands.

2- **Subcutaneous tissue:**

It is very loose and rich in elastic fibers. In whites, it is almost devoid of fat.

3- **Orbicularis oculi:**

It is a flat, elliptical muscle that surrounds the orbital margin extending onto the temporal region and cheek (orbital part) it also extends into the eyelids (palpebral portion) and further behind the lacrimal sac (lacrimal portion). It is composed of striated muscle.



The palpebral portion of the orbicularis oculi muscle consists of thin bundles of fibers that arise from the medial palpebral ligament; then these fibers sweep laterally across the eyelids and interlace at the lateral palpebral raphe.

- **Nerve supply:**

Temporal and zygomatic branches of the facial nerve.

4- **Orbital septum and tarsal plate:**

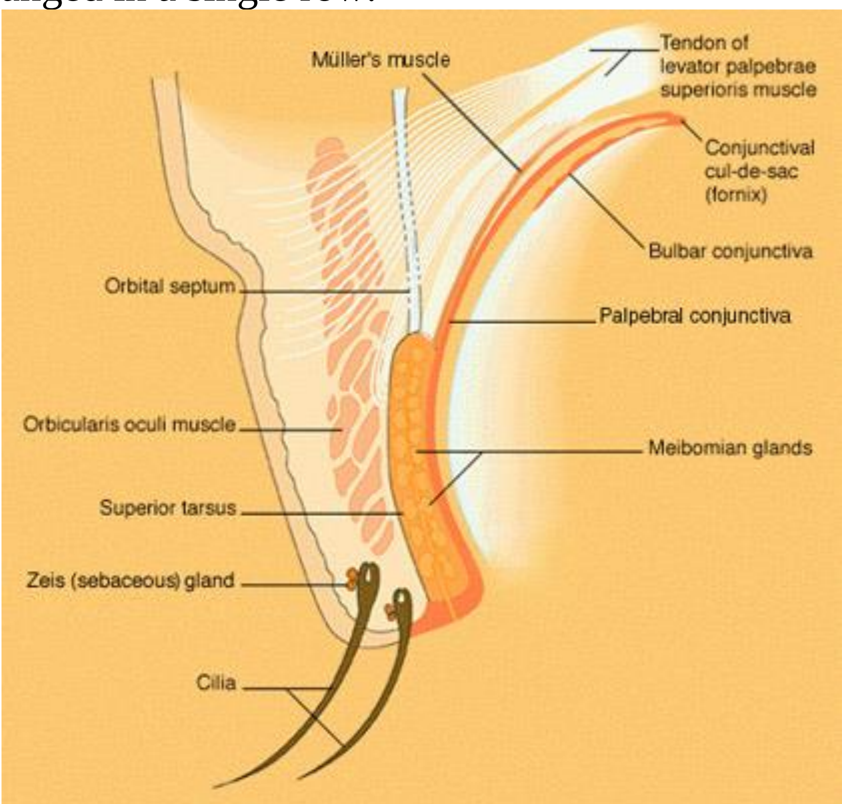
The fibrous framework of the eyelids is formed by a membranous sheet, the orbital septum. It is continuous with the periosteum (preiorbita).
The orbital septum acts as a diaphragm between the anterior and posterior part of the orbit so it prevents spread of the inflammation fluid and the blood between the anterior and posterior part of the orbit.

The tarsal plate consists of the dense fibrous tissue and gives the eyelids firmness and shapes.

The tarsal plate of the upper eyelid is much larger than the lower and is crescent shaped; each tarsus is approximately 29 mm long and 1 mm thick. The upper tarsus measures around 10 mm in the

center and gradually narrows towards its ends, and the lower one measures around 5 mm in height at the center and gradually narrows towards its end.

The tarsal glands (meibomian glands) are embedded within the substance of the tarsal plate; they are about 20 to 25 in each lid arranged in a single row.



5- **Smooth muscle:**

The smooth muscle forms the superior and inferior tarsal muscles.

The function of the superior tarsal muscle is to raise the upper lid and assist the striated muscle of the levator palpebrae superioris.

The function of the inferior tarsal muscle is to lower the lower lid. Paralysis of the smooth muscle results in drooping of the upper lid (ptosis).

6-**Conjunctiva:**

It is a thin mucous membrane that lines the eyelids and reflected at the superior and inferior fornices onto the anterior surface of the eyeball.

It covers part of the sclera, and its epithelium is continuous with that of the cornea.

It can be divided into three regions: palpebral, bulbar, conjunctival fornices.

❖ Levator palpebrae superioris:

The upper eyelid as distinct from the lower lid contains the insertion of a powerful striated muscle, the levator palpebrae superioris.

This muscle arises from the inferior surface of lesser wing of sphenoid and anterior to optic canal.

- Nerve supply:

The main striated part of the levator palpebrae superioris is supplied by the superior branch of the oculomotor nerve, the smooth muscle (superior tarsal muscle) is supplied by sympathetic nerves.

- Action:

The levator palpebrae superioris rises the upper eyelid .

Fear or excitement causes contraction of the smooth muscle (superior tarsal muscle) resulting in further elevation of the lid.

- Arterial supply of the eyelids:

The eyelids are supplied by the lateral and medial palpebral arteries.

- Venous drainage of the eyelids:

The veins of the eyelids, which are longer and more numerous than the arteries, drain into the ophthalmic and angular veins and laterally into the superficial temporal vein.

- Lymphatic drainage of the eyelids:

The lateral two-thirds of the upper and lower lids drain into the superficial parotid nodes.

Those from the medial angle drain into the submandibular nodes.

- Nerve supply of the eyelids:

The sensory innervation:

Innervation of the upper lids is from the infratrochlear, supratrochlear, supraorbital, and lacrimal nerves.

The skin of the lower lid is supplied by branches of the infratrochlear nerve at the medial angle.

The rest is supplied by branches of the infraorbital nerve.

- **Eyelid glands:**

There are four types of glands in the eyelid, they are:

1- Meibomian glands(tarsal glands):

Are sebaceous glands embedded in the tarsal plate , they produce a sebaceous substance which creates an oily layer on the surface of the tear film, this helps to prevent rapid evaporation of the normal tear layer.

2- Sebaceous glands of Zeis:

Smaller modified sebaceous glands which secrete sebum into the hair follicle to keep the eyelashes from becoming brittle.

3- Glands of Moll:

Are modified sweat glands located near the lid margin, their ducts empty into hair follicles, into the Zeis gland duct, or directly into the lid margin.

4- Accessory lacrimal glands (Krause and Wolfring):

They are formed beneath the palpebral conjunctiva; they supply most of the needed moisture to the conjunctival sac and cornea.

Conjunctiva

The conjunctiva is a thin mucous membrane which contains blood vessels and lines the eyelids and is reflected at the superior and inferior fornices on to the anterior surface of the eyeball. The conjunctival epithelium is continuous with the epidermis of the skin at the lid margin and with the corneal epithelium at the limbus.

General Arrangement

The conjunctiva can be divided into three regions:

- ❖ The palpebral conjunctiva.
- ❖ The conjunctival fornices.
- ❖ The bulbar conjunctiva.

Palpebral Conjunctiva:

It is very vascular, it lines the eyelids. It is firmly attached to the posterior surfaces of the tarsal plates.

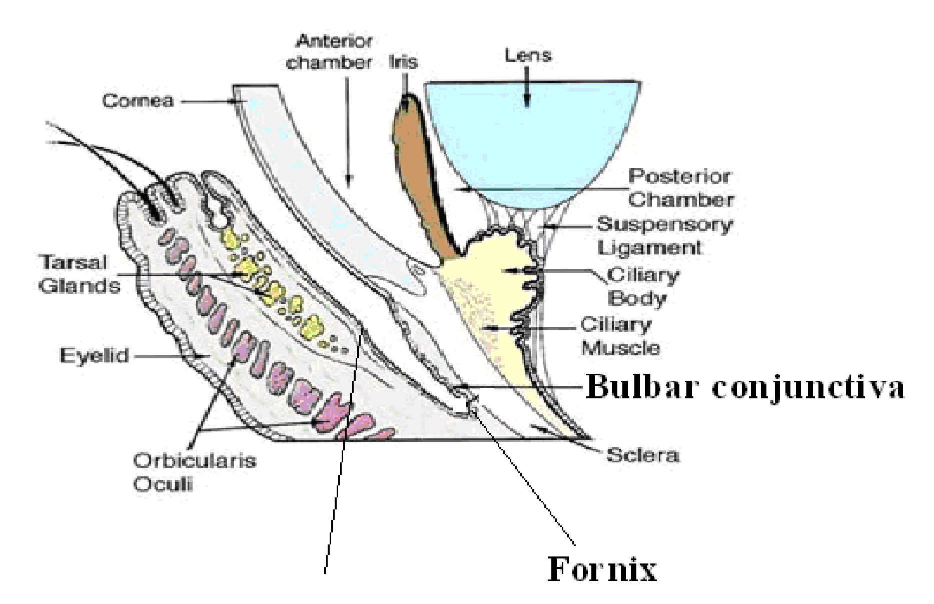
Conjunctival Fornices:

The conjunctiva of the superior and inferior fornices forms transitional regions between the palpebral and bulbar conjunctivae. It is loosely attached to the underlying facial expansions of the sheaths of the levator and recti muscles.

The superior fornix is deeper than the inferior fornix.

Bulbar (Ocular) Conjunctiva:

It is thin and transparent, and the underlying white sclera is clearly visible. It is loosely attached by connective tissue to the sclera.



Structure of the conjunctiva:

1. Epithelium:

It consists of stratified columnar cells consisting of two to five layers.

It is continuous with corneal epithelium. It contains goblet cells which secrete mucus.

2. Conjunctival submucosa:

It consists of fine delicate connective tissue which contains lymphocytes.

The deeper part of the submucosa contains denser fibrous tissue and the blood vessels, nerves, smooth muscle, and accessory lacrimal glands.

- Blood supply:

- Arteries:

1. Anterior conjunctival arteries which are branches from the anterior ciliary arteries.
2. Posterior conjunctival arteries.

- Veins:

The veins drain into the palpebral veins or into the superior and inferior ophthalmic veins.

- Nerve supply:

The bulbar conjunctiva innervates from the long ciliary nerves.

Innervation of the superior palpebral conjunctiva and superior fornix conjunctiva is from the frontal and lacrimal branches of the ophthalmic division of trigeminal nerve.

Sensory innervation of the inferior palpebral conjunctiva and inferior fornix is from the lacrimal branch of the ophthalmic division of trigeminal nerve and from maxillary division of trigeminal nerve.

- Lymphatic drainage:

- Lateral side: drain into the superficial parotid nodes.
- Medial side: drain into submandibular nodes.

Lacrimal Apparatus

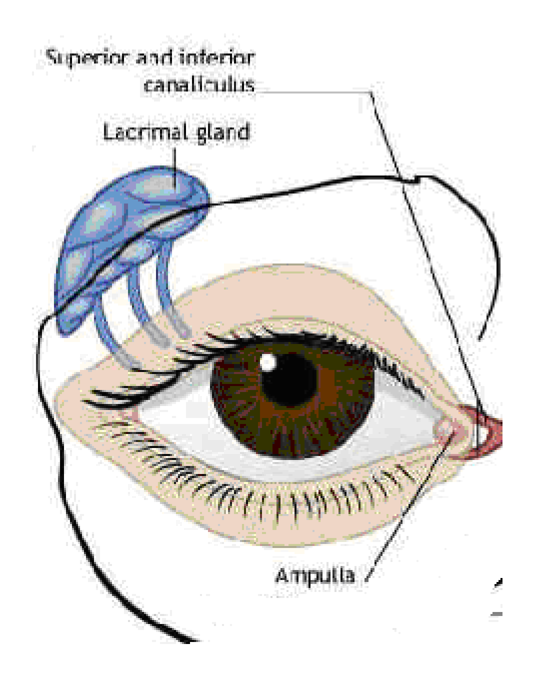
The lacrimal apparatus consists of two parts:
1- Secretory part of tear.
2- Drainage part of tear.

1- Secretary part
Consist of the main lacrimal gland and the accessory lacrimal glands (Krause and Wolfring).

- **Main lacrimal gland**: it is superiolateral in the orbit and has two parts: large upper orbital and smaller, lower palpebral part.

  - Structure of lacrimal gland:

The lacrimal gland is lobulated and tubulo-acina in form; its secretory units are acini.



Accessory glands:

I. Krause: it is micro glands located in superior and inferior fornices; they are about 40 glands in the superior fornix and 8 in the inferior fornix. And they drain it's secretions in the fornices.

II. Wolfring glands: they are identical glands located beside the margin of tarsal plate.

2- Tear drainage part:

Punctum Lacrimale :

The punctum lacrimale is a small round or oval orifice situated on the summit of a small projection, the papilla lacrimalis, at the medial end of the lid margin.

Lacrimal Canaliculi :

There is one lacrimal canaliculus in each lid, the walls of the canaliculi are thin and elastic; each canaliculus measures about 10 mm long and consists of a vertical and a horizontal portion. The vertical part is around 2 mm long and the horizontal part is about 8 mm long.

The upper canaliculus runs medially and downward; the lower one, medially and upward.

lacrimal sac:

It is situated in the lacrimal fossa in the medial wall of the orbit; it is about 12 mm long.

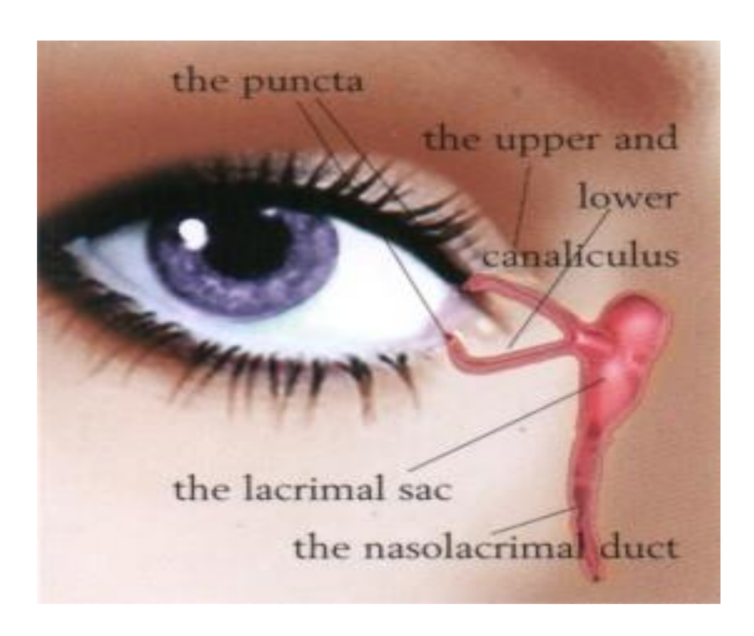
The wall of the lacrimal sac consists of fibro-elastic tissue and is lined with two layers of columnar cells.

Nasolacrimal Duct

The nasolacrimal duct, about 18 mm long, connects the lower end of the lacrimal sac with the inferior meatus of the nose. It is narrower in the middle than at either end. The direction of the duct is downwards, backward, and lateral.

At the opening of this duct to the nose there is Hasner valve, this valve prevents the back movement of the fluid to the duct from the nasal cavity.

The sudden contraction of the lacrimal part of the orbicularis oculi muscle causes dilatation of the lacrimal sac resulting in the tears being sucked into the sac.



❖ Tear Film:

It covers the anterior surface of the globe. It is somewhat basic (PH 7.35). The precorneal tear film is composed of three layers:

1. **Thin superficial oily layer**: it is produced predominantly by the tarsal (meibomian) gland and to a slight extent by the sebaceous glands (zeiss) and sweat glands (Moll).

This layer inhibits evaporation of the underlying watery layer.

2. **The thick, watery layer**: it is secreted by the main and accessory lacrimal glands.

This layer contains glucose, inorganic salts, enzymes, proteins, lysozymes, immunoglobulin, which defense against invading organisms.

3. **The thin mucin layer**: it is secreted by the conjunctival goblet cells and from lacrimal gland cells.

The lacrimal gland secretes tear around 9.5 ml during the day and about 50% of it evaporate and the remainder go through the lacrimal ducts.

- Blood supply to the lacrimal gland:

Lacrimal artery a branch from the ophthalmic artery.
The venous drainage is into the ophthalmic vein.

- Lymphatic drainage:

Joins that of the conjunctiva and passes to the superficial parotid lymph nodes.

- Nerve supply:

The sensory innervation is by the lacrimal nerve a branch of the ophthalmic division of the trigeminal nerve.

Chapter Four

The Eyeball

Fascial Sheath of the Eyeball

- **Fascial sheath of the eyeball(fascia bulbi, Tenon's capsule):**

It is a thin membrane that envelops the eyeball and separates it from the orbital fat.

The main function of this sheath is to position and support the eyeball and permit the actions of the extrinsic muscles to produce movement of the eyeball.

- **The eyeball**:

The eyeball consists of two segments: the anterior smaller segment is transparent and forms about one-sixth of the eyeball (cornea). And the posterior larger segment is opaque and forms about five-sixth of the eyeball.

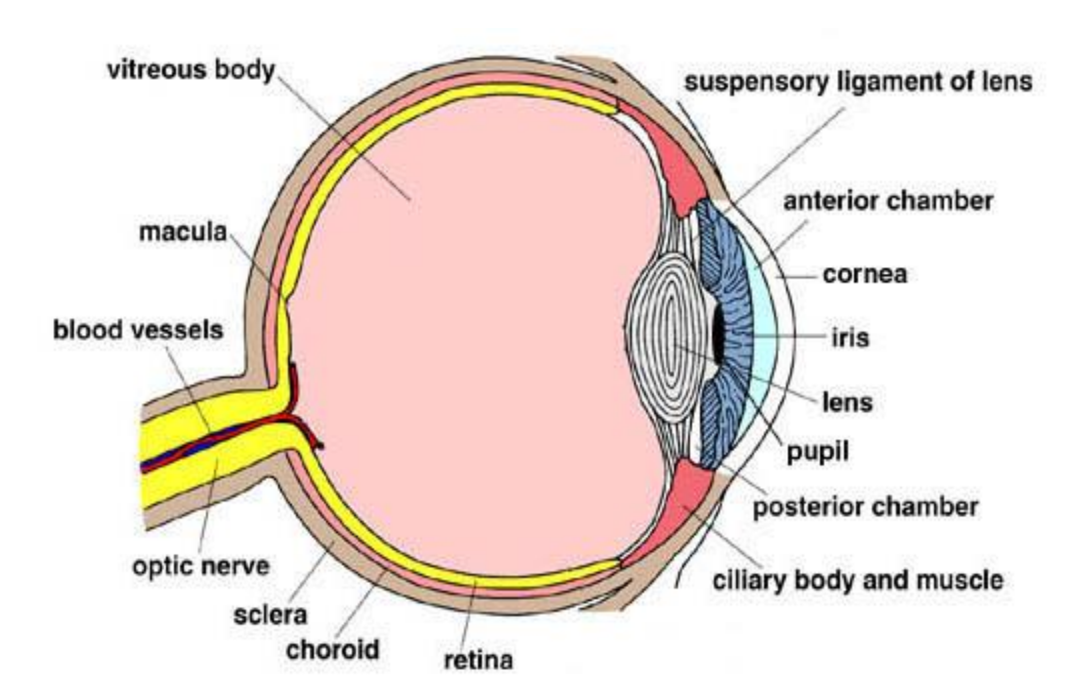
The anterioposterior diameter of the eye measures about 24 mm.

The eyeball situated in the anterior part o the orbital cavity closer to the roof than the floor and nearer the lateral than the medial wall.

❖ Layers of the Eyeball:

The eyeball consists of three layers which are:

1. The outer fibrous layer(sclera and cornea)
2. The middle vascular layer(uveal tract)
3. The inner neural layer(the retina)



١. The Fibrous layer:

It is made of a posterior opaque part the sclera and an anterior transparent part the cornea.

The Sclera

- Anatomy of the sclera:

The sclera forms five-sixths of the eyeball and it is opaque (usually white), fibrous, protective layer of the eye which contains collagen and elastic fibers

In the adult the sclera is about 1 mm thick posteriorly, thinning at the equator to 0.6 mm. It is thinnest, 0.3 mm, immediately posterior to the tendinous insertions of the recti muscles.
At the corneoscleral junction the sclera is 0.8 mm thick.

The medial rectus inserts 5.5 mm posterior to the limbus, the inferior rectus 6.5 mm, the lateral rectus 6.9 mm, and the superior rectus 7.7 mm. The insertions of the superior oblique and inferior oblique muscles are posterior to the scleral equator.

Anteriorly, the sclera is directly continuous with the cornea at the limbus (sclero corneal junction or corneo scleral junction)

Just posterior to the limbus, and lying within the sclera, is a running canal called the sinus venous sclera (the canal of Schlemm).

Posterior to the canal is a projecting ridge of scleral tissue known as the scleral spur, it is triangular in cross section and it gives attachment to the ciliary muscle.

Structure of the sclera:

The sclera is divided into three layers:

1- Episclera:

It is the outermost layer and consists of loose connective tissue; it is connected to the fascial sheath of the eyeball (Tenon's capsule).

It has a rich blood supply from the anterior and posterior cilliary arteries; it becomes progressively thinner toward the back of the eye.

2- Scleral stroma:

It consists of dense fibrous tissue and fine elastic fibers; the irregular arrangement of the collagen fibrils is largely responsible for the opacity of the sclera in contrast to the transparency of the cornea where the fibrils run parallel with the surface.

3- Lamina fusca:

It is the innermost layer of the sclera; it is faintly brown because of the presence of melanocytes, which form a thin, irregular layer.
It is separated from the external surface of the choroids by a potential space (the perichoroidal space).

Scleral foramens and apertures:

- The sclera is perforated posteriorly about 3 mm medial and 1mm above the posterior pole of the eyeball by the optic nerve; the site of this perforation is sometimes referred to as the *posterior scleral foramen.*

- Lamina cribrosa:

It is a weak, sieve-like appearance where the optic nerve fibers pierce the sclera; it transmits the central retinal artery and vein.

It is the weakest area in the sclera, so it may bend to the back in case of glaucoma, and form the glaucomatous cup.

* The sclera is also pierced by three groups of small apertures:

1. **Anterior apertures**:

They are located at the insertion of the recti muscles and are for branches of the anterior ciliary arteries.

Each rectus muscle has two anterior ciliary arteries with the exception of the lateral rectus muscle which only has one.

2. **Middle apertures**:

They are situated about 4 mm posterior to the equator of the eye and number about four to five. They are for the exit of the vortex veins.

3. **Posterior apertures:**

They are small and numerous and located around the optic nerve. They transmit the long and short ciliary nerves and vessels.

- Colour of the sclera:

In the adult the sclera is white, but in children the sclera is thin and so the pigment cells of the choroid show through, giving the sclera a bluish colour.

In the elderly the sclera may have a yellowish colour from the deposition of fat.

- Blood supply :

The arterial supply is by anterior ciliary arteries, short and long posterior ciliary arteries.

- Nerve supply:

By the short and long ciliary nerves.

- Sinus venosus sclera (Canal of Schlemm) :

It is a canal lined with endothelium, it is like a veins instead that it contains aqueous humor not blood.
From this canal the aqueous humor outflows from the anterior chamber to the aqueous veins and then it drains into anterior ciliary veins, and also the aqueous humor may outflows from the canal of Schlemm to the intrascleral plexus and then into the anterior ciliary veins.

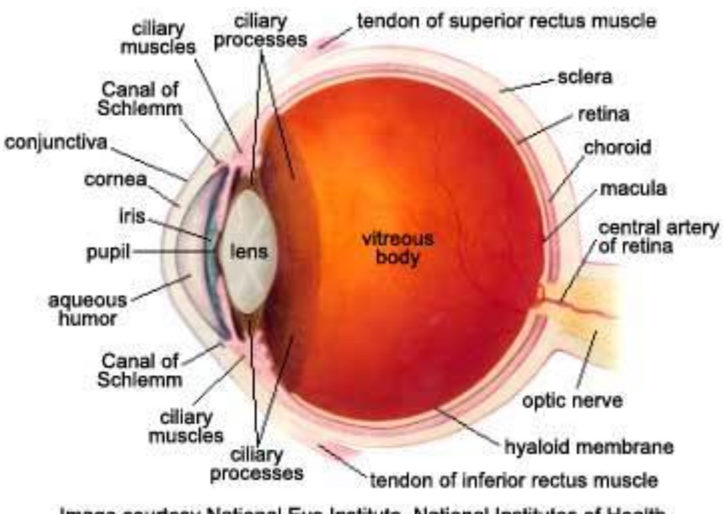


Image courtesy National Eye Institute, National Institutes of Health

The Cornea

It is transparent, and forms the anterior one-sixth of the eyeball. The radius of curvature of the anterior surface is about 7.7 mm and that of the posterior surface is 6.8 mm. the average curvature 8.00 mm.

It is the main structure responsible for the refraction of light, its refractive power about 43.00 diopters (about 75%of the dioptric power of the eye).

It has an elliptical shape which measures about 10.6 mm vertically and 11.7 mm horizontally.

Its thickness is 0.5-0.6 mm in the centre and 1.00 mm in the periphery (limbus).

It separates the air that has a refractive index about 1 from the aqueous humor that refractive index about 1.33

It has rich innervations and so it is highly sensitive.

The refractive index of the cornea is about 1.376

- Structure of the cornea:

The cornea consists of five layers:

1. The epithelium:

It consists of five layers of cells.
The deepest are columnar and the cells in the second layer are polyhedral, and the superficial layer consists of squamous cells.

The epithelium layer regenerates rapidly.

Its thickness is about 50μm

2. Bowman's membrane:

It lies immediately beneath the basement membrane of the corneal epithelium and it contains a dense mass of collagen fibrils.

It does not regenerate, and so if it is broken by trauma or infection it will leave a scar on the cornea, its thickness is about 8-12 μm.

3. Stroma (Substantia propria):

It constitutes 90% of the corneal thickness and it is the primary structural component.

It consists mainly of collagen fibers (mainly type I collagen with small amount of type III, V, and VI) which run from limbus to limbus in bundles called lamellae.

When damaged the stoma is replaced by a fibrous tissue and so leave a scar.

Its thickness is about 450 μm.

4. Descemet's membrane:

It is elastic and separates the corneal stroma from the endothelium, it is composed of a meshwork of collagen fibers, unlike bowman's layer, it detaches easily from the stroma and regenerates after injury. It thickens with age.

Its thickness is about 10 μm.

5. Endothelium:

It consists of a monolayer of polygonal, flattened cells which separates the corneal stroma from the anterior chamber.

It has an important role of keeping the cornea relatively dehydrated and maintaining the corneal transparency.

It has minimal regeneration capacity for purposes of repair,it doesn't replicate but increase in size to relief defects.

It regulates the flow of electrolytes and fluid between cornea and anterior chamber.

Its thickness is about 5 µm.

- The transparency of the cornea is due to many factors such as:

1. Regular pattern in which the corneal lamellae are laid down which allows the rays of light to pass through without interruption.

2. Avascular (the cornea does not have any blood vessels).

3. No pigments.

4. The cornea is relatively dehydrated (the action of a pump system in the cells of the endothelium and epithelium which pump water out the cornea against an osmotic gradient.

5. The tight junctions between endothelial cells that doesn't permeable of aqueous solutions.

- Nerve supply to the cornea:

The cornea is supplied by the long ciliary nerves which branches from the ophthalmic division of trigeminal nerve.

The cornea is very sensitive, so any infection or injury will be so painful.

- The limbus(corneoscleral junction or sclerocorneal junction):

It is the area which the cornea continues with the sclera.

It is about 1.5-2.00 mm wide.

In this area many connection happens such as:

1. The corneal epithelium becomes the epithelium of the bulbar conjunctiva.

2. Bowman’s layer becomes continuous with the lamina propia of the conjunctiva and the fascial sheath of the conjunctiva.

3. Descemet’s membrane continues with trabecular meshwork.

4. Corneal endothelium becomes continuous with the anterior surface of the iris.

2. The vascular pigmented layer:
Uveal Tract

- Vascular pigmented layer(Uveal tract):

The iris, ciliary body, and the choroid forms what is called by the uveal tract. And it is the middle layer of the eyeball.

- ***Choroid:***

It is a thin, soft, brown coat lining the inner surface of the sclera, and it is extremely vascular.

It consists largely of a dense capillary plexus, with its small arteries and veins.

It is thickest at the posterior pole (about 0.22mm) and gradually thins anteriorly about 0.1mm.

Between sclera and choroid is a potential space, the perichoroidal space. Running across this space are thin, pigmented sheets of connective tissue called the suprachoroid lamina.

- Structure of the choroid:

It can be divided into three layers:

1) The vessel layer:

It consists of loose connective tissue containing melanocytes in which are embedded numerous blood vessels, these vessels are arranged into two layers:

I. Haller's layer: this outer layer composed of large vessels, the majority of it is veins.

II. Sattler's layer: this inner layer composed of small vessels.

2) the capillary layer:

This layer consists of numerous choriocapillaries, these capillaries are supported by delicate connective tissue containing melanocytes.

3) Bruch's membrane:

This inner homogeneous layer measures 2 to 4 µm thick and consists of five different components:
1) The basement membrane of the choriocapillaries.
2) An outer layer of collagen fibers.
3) A meshwork of elastic fibers.
4) An inner layer of collagen fibers.
5) The basement membrane of the pigment epithelium of the retina.

- Blood Supply:

- From the posterior ciliary arteries a branch of the ophthalmic artery.
- Vorticose veins drain the choroid and pierce the sclera to join the ophthalmic veins.

- Nerve Supply:

The choroid is innervated by the long and short ciliary nerves. The innervation of the blood vessels is by the sympathetic fibers for its contraction and by the parasympathetic fibers for its relaxation.

❖ *Ciliary body:*

The ciliary body is continuous with the choroid behind and with the iris infront. The ciliary body is triangular on cross-section with its small base facing the anterior chamber of the eye and its anterior outer angle facing the scleral spur.

The anterior surface or base is ridged or plicated and is called the pars plicata the posterior surface is smooth and flat and is called the pars plana. It is the pars plicata that surround the periphery of the iris and gives rise to the ciliary processes.

Ciliary processes: vascular folds on the inner surface of the ciliary body that give attachment to the suspensory ligaments (zonules) of the crystalline lens.

- Structure of the ciliary body:

1. Ciliary Epithelium:

Two layers of cubical cells that cover the inner surface of the ciliary body.

The two layers are the nonpigmented inner layer and the pigmented outer layer.

2. Ciliary stroma:

The ciliary stroma consists of bundles of loose connective tissue rich in blood vessels and melanocytes.

It lies between the two epithelial layers and the ciliary muscle, and forms the core of each of the ciliary processes.

3. Ciliary muscle:

The ciliary muscle forms the bulk of the substance of the ciliary body and it consists of smooth muscle fibers, it serves as the chief agent in accommodation when it contracts by drawing the ciliary processes centripetally and relaxing the suspensory ligament of the crystalline lens, the lens becomes more convex.

The muscle fibers may be divided into three main groups:

1. Longitudinal or meridional fibers:

The most external and closest to the sclera, pass posteriorly into the stroma of the choroid.

2. Oblique or radial fibers:

They run from the first layer to the third layer, and originate from the scleral spur.

3. Circular fibers:

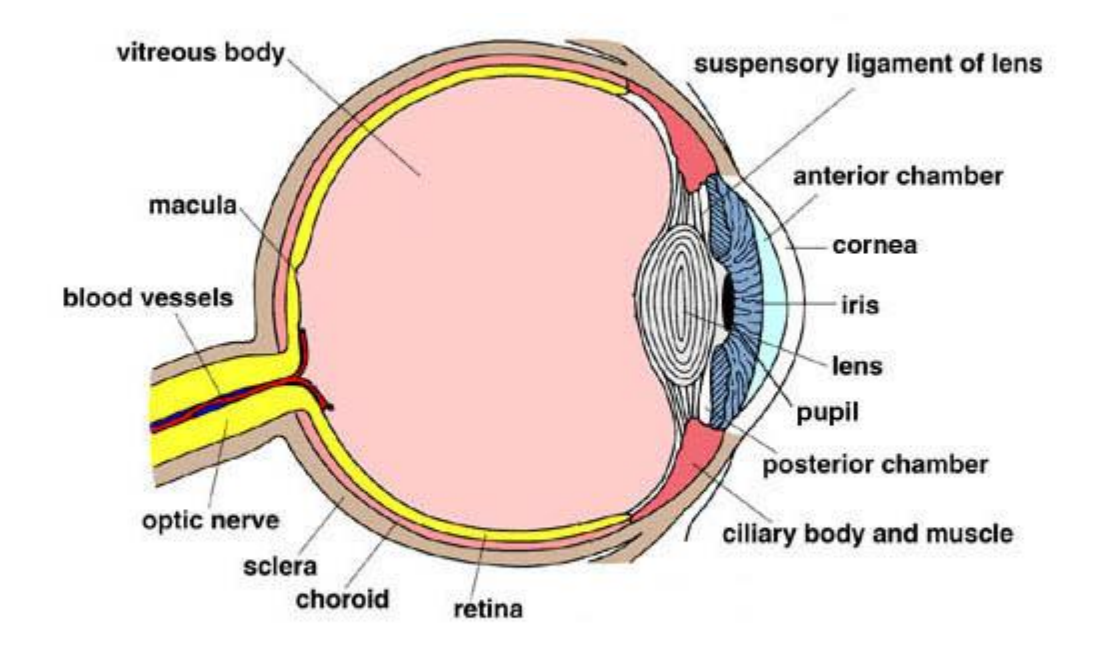
The most internal, they lie near the periphery of the lens.

- Blood supply:

- By the major arterial circle of the iris.
- By the vortex veins and the ciliary veins.

- Nerve supply:

The ciliary muscle is innervated by the parasympathetic fibers derived from the oculomotor nerve.



❖ ***Iris:***

It is the anterior part of the uveal tract.

It is thin, contractile, pigmented diaghram with a central aperture, the pupil. It is suspended in the aqueous humor between the cornea and the lens.

The pupil (a small hole in the middle of the iris) controls the amount of light entering the eye; pupillary diameter varies from 1 to 8 mm at least and has an even wider range under the influence of drugs.

The iris divides the space between the cornea and the lens into anterior and posterior chambers.

The color of the iris varies from light blue to dark brown; the color of the iris is produced by the pigment in the melanocytes.

The anterior surface of the iris is divided into two zones by the collarette (a circular ridge approximately 2 mm from the pupillary margin).

1. Central pupillary zone: it encircles the pupil.

2. Peripheral ciliary zone: it extends from the collarette to the iris periphery.

Structure of the iris:

- Microscopically the iris consists of two layers:

1. The stroma:

It consists of highly vascular connective tissue containing collagen fibers, fibroblast, melanocytes, and matrix.

It is also contains nerve fibers, the smooth muscle of the sphincter pupillae, and the myoepthelial cells of the dilator pupillae.

- The sphincter pupillae muscle:

It is located in the pupillary zone of the iris. It forms a ring of smooth muscle fibers around the pupil, measuring about 1 mm wide.

When it contracts, the pupil constricts (miosis). The nerve supply for this muscle is by the parasympathetic fibers which derived from the oculomotor nerve.

- The dilator pupillae muscle:

It is a thin layer of myoepithelium that extends from the iris root as far as the sphincter pupillae; it is arranged in a radial pattern.

When it contracts, the pupil enlarges (mydriasis). The nerve supply for this muscle is by the sympathetic ganglion via the long ciliary nerves.

The dilator muscle is weaker and larger than the sphincter muscle.

2. Two epithelial layers:

They are two epithelial layers one called anterior and the other posterior. These cells are apposed to each other apex to apex.

- The anterior epithelial layer:

It lies in contact with the stroma of the iris. It contains relatively few melanin granules.

- The posterior epithelial layer:

It is bathed with aqueous humor and faces the posterior chamber.

The cells are larger than those of the anterior layer and are cuboidal in shape. They are packed with melanin granules.

- Blood supply:

The arterial supply of the iris is provided by radial vessels that lie in the iris stroma, the arteries arise from the *major arterial circle* located in the stroma of the ciliary body, and the major arterial circle is formed from the two long posterior ciliary arteries and the seven anterior ciliary arteries.

On reaching the collarette, the arteries anastamose to form an incomplete *minor arterial circle* of the iris.

The veins follow the arteries and form a corresponding minor venous circle.

The radial veins do not drain into a major venous circle but converge and drain into the vorticose veins.

- Nerve supply:

The iris receives its sensory and autonomic nerve supply from the long and short ciliary nerves.

The Retina

This nervous layer, or retina, is the internal layer of the eyeball.

The retina is a thin transparent membrane having a purplish-red color in living subjects. Its thickness varies from 0.56mm near the optic disc to 0.1 mm at the ora serrata, and it is thinnest at the centre of the fovea.

The retina is firmly attached at the margins of the optic disc and at its anterior termination at the ora serrata.

The retina consists of an outer pigmented layer and an inner neurosensory layer.

The optic nerve leaves the retina about 3mm to the medial side of the macula lutea at the optic disc, the optic disc is about 1.5 mm in diameter and is a pale pink in color, much paler than the surrounding retina. It is slightly depressed at its center where it is pierced by the central retinal artery and vein. At the optic disc there is a complete absence of rods and cones; thus it is insensitive to light and is referred to as the “blind spot”.

The retina consists of ten layers:

1**. Retinal pigment epithelium:**

(Often abbreviated RPE) consists of a single layer of pigmented hexagonal cells that extends forward from the margin of the optic nerve to the ora serrata anteriorly.
The cells are narrow and tall in the posterior polar region and become flattened near the ora serrata.

The attachment of the RPE to the Bruch's membrane of the choroid is stronger than its attachment with the retina, so that lead to form a space between the RPE and the remain nine retinal layers, this space may be full with aqueous in certain cases and causes the retinal detachment.

2- **Photoreceptors layer (rods and cones):**

There are two types of photoreceptors the rods and the cones. The rods are mainly responsible for vision in dim light and produce images consisting of varying shades of black and white while the cones are adapted to bright light and can resolve fine details and color vision. The total number of the rods in the retina has been estimated to be about 110 to 125 million and of the cones 6.3 to 6.8 million.

The rods are absent at the fovea rising rapidly in number toward the periphery. The cones, on the other hand are most dense at the fovea and the numbers decrease at the periphery.

The rod cells are slender cells and the outer segment is the true photoreceptor of the cell and contains the photosensitive pigment rhodopsin.

The cone cells are also long slender cells. They have a structure similar to that rod except that the conical outer segment is wider than a rod at its base. Several photochemicals are found in the cones; they are similar in composition to rhodopsin and are known as iodopsins.

3- **The external limiting membrane:**

It is not a true membrane but actually consists of intercellular junction between photoreceptors cells and Muller cells.

4- **The outer nuclear layer :**

It contains rods and cones nuclei.

5- **The outer plexiform layer:**

It consists of synapses between the rods and cons nuclei and the bipolar cells.

6- **The inner nuclear layer:**

It consists of horizontal cells, bipolar cells, amecrine cells interplexiform cells, and Muller cells.

7- **The inner plexiform layer:**

This layer is made up of the synaptic connections between the bipolar, amecrine and ganglion cells.

8- **The ganglion cell layer:**

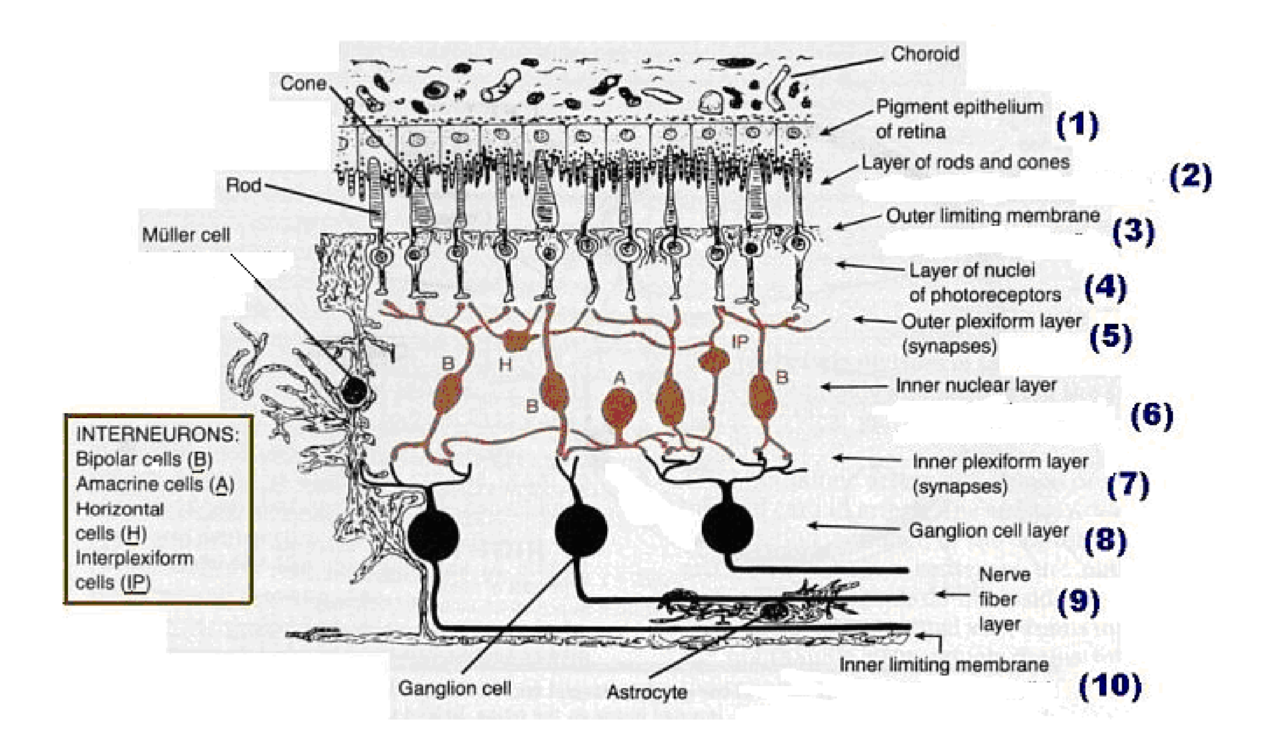
It consists of the nuclei of the ganglion cells.

9- **The nerve fiber layer:**

It consists of the axons of the ganglion cells that are converging toward the optic disc.

10-The internal limiting membrane:

It composed of expanded termination of Muller cells.

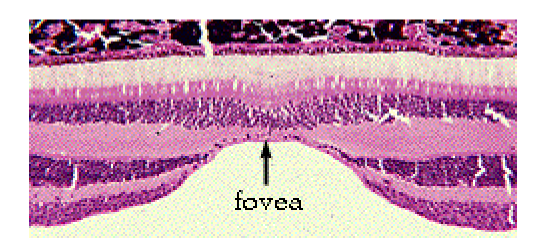

Choroid
Cone
Pigment epithelium of retina
(1)
Layer of rods and cones
(2)
Rod
Outer limiting membrane
(3)
Müller cell
Layer of nuclei of photoreceptors
(4)
Outer plexiform layer (synapses)
(5)
IP
B
H
A
B
B
Inner nuclear layer
(6)
INTERNEURONS:
Bipolar cells (B)
Amacrine cells (A)
Horizontal cells (H)
Interplexiform cells (IP)
Inner plexiform layer (synapses)
(7)
Ganglion cell layer
(8)
Nerve fiber layer
(9)
Inner limiting membrane
(10)
Ganglion cell
Astrocyte

Specialized Areas of the Neural Retina:

Macula Lutea and Fovea Centralis:

The macula is an oval yellowish area at the center of the posterior part of the retina. It measures about 5mm in diameter and lies about 3mm to the lateral side of the optic disc. The yellow coloration of the macula is caused by a yellow caroteniod pigment xanthophylls which is present in the retinal layer from the outer nuclear layer inward.

A depressed area in the center of the macula lutea is called the fovea. There are no blood vessels in the fovea and no rod cells in the floor of the fovea. Here it is the highest concentration of cones (147.000 per square millimeter).



Ora Serrata:

The ora serrata is the scalloped anterior margin of the retina. Here the nervous tissues of the retina end. The ora serrata is about 8.5 mm from the limbus.

❖ Optic nerve:

It is also known as cranial nerve II, its nerve fibers are the axons of the ganglion cells; they converge on the optic disc.

About 1.200.000 myelinated axons make up the optic nerve.

It acts like a cable connecting the eye with the brain.

- **Blood supply:**

The blood supply of the retina is from two sources:

1) The outer lamina, including the rods, cones and outer nuclear layer are supplied by the choroidal capillaries.
2) The inner laminae are supplied by the central retinal artery a branch of ophthalmic artery.

The venous drainage of the optic nerve is into the central vein of the retina.

❖ Blood retinal barrier:

The neural retina is protected from large molecular toxic substances by a barrier.

The outer third is protected by the tight junctions that close off the spaces between pigment epithelial cells of the pigment layer of the retina. The remainder is protected from the tight junctions that close off the spaces between the non fenestrated endothelial cells of the retinal capillaries.

Chambers of the eyeball

Anterior chamber:

It is a small cavity lying behind the cornea and in front of the iris it is filled with aqueous humor. Its volume is about 0.2 ml. it measures about 3 mm anteroposteriorly in its central portion.
It should be noted that the anterior chamber is bounded in front by the cornea and a small area of the sclera. Posteriorly, the chamber is bounded by the anterior surface of the iris, a small area of the anterior surface of the lens exposed by the pupil, and a part of the ciliary body.

The center of the chamber is deeper than the periphery; its shape is like a dome.

If any defect happens like the anterior adhesion between the iris and the cornea or posterior adhesion between the iris and the lens, sometimes posterior and peripheral attachments occur at the same time, so the depth increase at the center and decrease at the peripheral area which leads to change the shape of the chamber to become like a cone.

Posterior chamber:

It is a small slit like cavity; it is bounded anteriorly by the iris, peripherally by the ciliary processes, and posteriorly by the lens. Its volume is about 0.06 ml. the posterior chamber is filled with aqueous humor and communicates through the pupil with the anterior chamber.

Aqueous humor:

Is a clear fluid that fills the anterior and posterior chambers of the eyeball.

The ciliary processes of the ciliary body are responsible for its production by diffusion from the capillaries and by active transport from the unpigmented ciliary epithelium.

The rate of formation is about 1-2μL per minute.

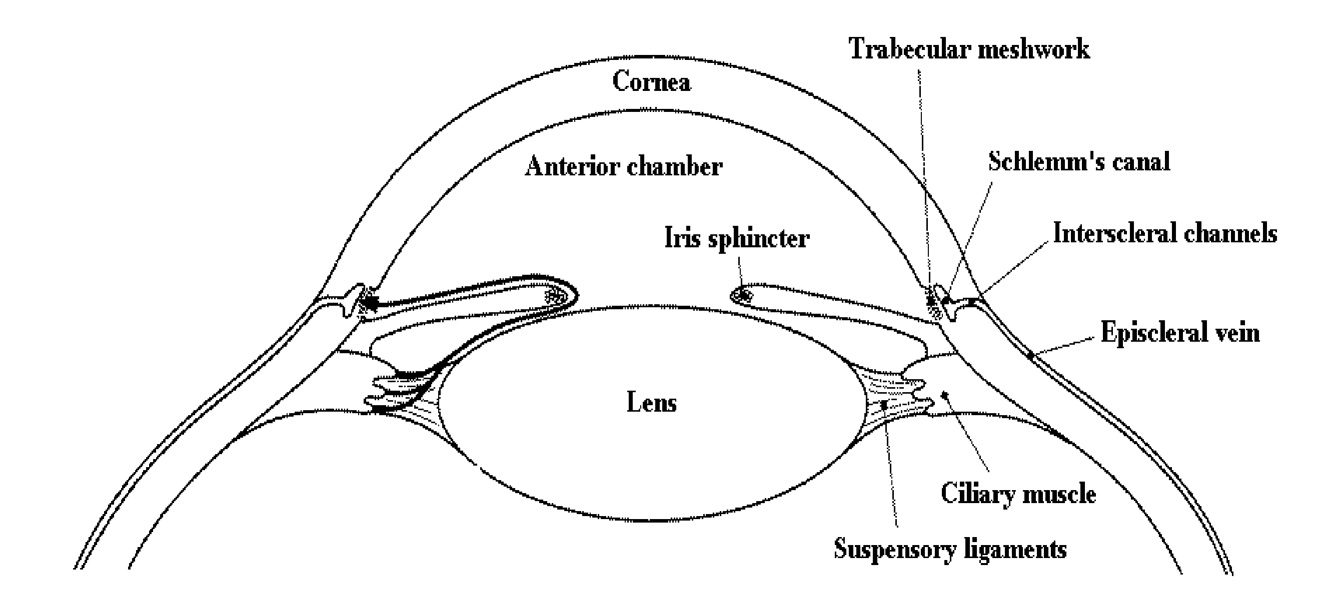
The aqueous humor resembles blood plasma in composition, but contains much less protein, less glucose, more lactic acid, and much more ascorbic acid.

Compositions:

-Water: 99%-
-Ions: buffers metabolic acids; Cl^-, Na+; K+; Ca2+;
-Proteins: albumin, β-globulins
-Ascorbate: anti-oxidative, protects against U.V
-Glucose
-Amino acids

- ***Circulation and drainage of the aqueous humor***:

The aqueous humor flows to the anterior chamber through the pupil and then ninety percent of the outflow occurs through the trabecular meshwork, sinus venous sclerae, the collector channels, and the aqueous veins. The remaining ten percent of the outflow occurs through the anterior surface of the ciliary body, where it enters the extracellular spaces and diffuses into the suprachoroidal space to enter the vortical veins.



❖ ***Blood-aqueous humor barrier***:

-The blood-aqueous humor barrier is formed by the tight junctions of the nonpigmented ciliary epithelium.

The Crystalline Lens

The lens is a transparent biconvex structure placed between the iris and the vitreous body.

The center point on its anterior and posterior surface are referred to as the anterior and posterior poles respectively; a line joining the poles forms the axis of the lens; the marginal circumference of the lens is called the equator.

The dioptric power of the entire eye is about 58 diopters with the cornea responsible for most of this refractive ability. The lens contributes only about 15 diopters to the total power, and its refractive index is 1.42.

The lens continues to grow throughout life, measuring about 6.5 mm in diameter at birth and 10.00 mm in the adult. Average adult radii of curvature of the anterior and posterior surface are 10 mm and 6 mm respectively. It also increases in thickness, the thickness possibly reaching 5 mm in the aged.

The lens is avascular, and this is one cause of its transparency.

The lens is held in position by a series of delicate, radially arranged fibers collectively known as the suspensory ligament of the lens, or zonules. The zonule fibers arise from the epithelium of the ciliary processes and run toward the equator of the lens.

❖ Structure of the lens:

1. Lens capsule:

It is a thick, elastic, semi permeable membrane that envelops the entire lens.
It is secreted by the epithelial cells which lie beneath it; it is thickest on the anterior and posterior surfaces close to the equator, and thinnest at the posterior pole.

2. Lens epithelium:

The lens epithelium is cuboidal and lies beneath the capsule. It is found only on the anterior surface of the lens at the equator these cells elongate and form columnar cells.

3. Lens fibers:

These fibers constitute the main mass of the lens. The fibers are formed by the multiplication and differentiation of the lens epithelial cells at the equator.

The new fibers arranged around the old fibers which are pushed toward the centre of the lens, and then they become dehydrated to form the nucleus.

The earliest lens fiber mass in the center is called the embryonic nucleus; it is followed by the fetal nucleus. And the fibers which are formed after birth is known as adult nucleus and the area surrounding the adult nucleus is known as the lens cortex.

Vitreous body

The vitreous body fills the eyeball behind the lens. It thus occupies about four-fifths of the eyeball and lies between the lens and the retina.

In the region of the pars plana of the ciliary body and the adjacent ora serrata is an attachment that is known as the vitreous base.

The vitreous is also attached to the neural part of the retina, at the margin of the optic disc. Behind the lens, the vitreous is attached to the lens along the periphery of the hyaloid fossa; this attachment is particularly firm in the young and weakens with age.

The vitreous is a colorless, transparent gel consisting of 99% water. It has a refractive index of 1.33 and possesses an organized network of fine collagen fibrils.

- **Vitreous humor has the following composition:**

1) Water (99%)
2) A network of collagen fibrils
3) Large molecules of hyaluronic acid
4) Peripheral cells (hyalocytes)
5) Inorganic salts
6) Sugar
7) Ascorbic acid
8) Soluble proteins.

- Hyaloid canal:

A narrow 1 to 2 mm wide runs forward from the optic disc to the posterior pole of the lens. During fetal life it contains the hyaloid artery. The hyaloid artery is a branch of the central retinal artery, the hyaloid artery disappears about 6 weeks before birth, and the canal becomes filled with liquid.

- **Transparency of the vitreous is due to many factors:**

1. The integrity of its structures functionally and structurally.

2. The absence of abnormal liquids such as blood or pus.

3. The absence of any strange cells like fibers in case of retinal fibrosis or blood vessels or cholesterol crystals.

Note: the vitreous humor cannot be recovered; instead it is replaced by the aqueous humor.

Chapter five

The Extraocular Muscles

The Extraocular Muscles

There are six extraocular muscles which produce eye movements, four recti muscles and two obliques muscles.

- The four recti muscles are:

1. The superior rectus muscle (S.R).
2. The inferior rectus muscle (I.R).
3. The medial rectus muscle (M.R).
4. The lateral rectus muscle (L.R).

- The two oblique muscles are:

1. The superior oblique muscle (S.O).
2. The inferior oblique muscle (I.O).

The four rectus muscles arise from the back of the orbit in a fibrous ring called the common tendinous ring “annulus of Zinn”.

Note: The oblique muscles form an angle about 51° with the visual axis in which the rectus muscles form an angle about 23° with the visual axis.

From this common origin the rectus muscles pass forward as a muscle cone to be inserted into the sclera of the eyeball at a specific distance from the limbus.

1. The tendon of the medial rectus muscle inserts 5.5 mm posterior to the limbus along the medial aspect of the globe.

2. The tendon of the inferior rectus muscle inserts 6.5 mm posterior to the inferior limbus.

3. The tendon of the lateral rectus muscle inserts 6.9 mm posterior to the lateral limbus.

4. The tendon of the superior rectus muscle inserts 7.7 mm posterior to the superior limbus.

⇒ Origins of the extraocular muscles:

❖ The superior rectus muscle:

It arises from the orbital roof above the optic foramen and from the annulus of Zinn which surrounds the optic nerve.

❖ The inferior rectus muscle:

It arises from the orbital floor below the optic foramen and from the annulus of Zinn.

❖ The medial rectus muscle:

It is the largest of the extraocular muscles.

It arises from the medial wall, and from annulus of Zinn.

- The lateral rectus muscle:

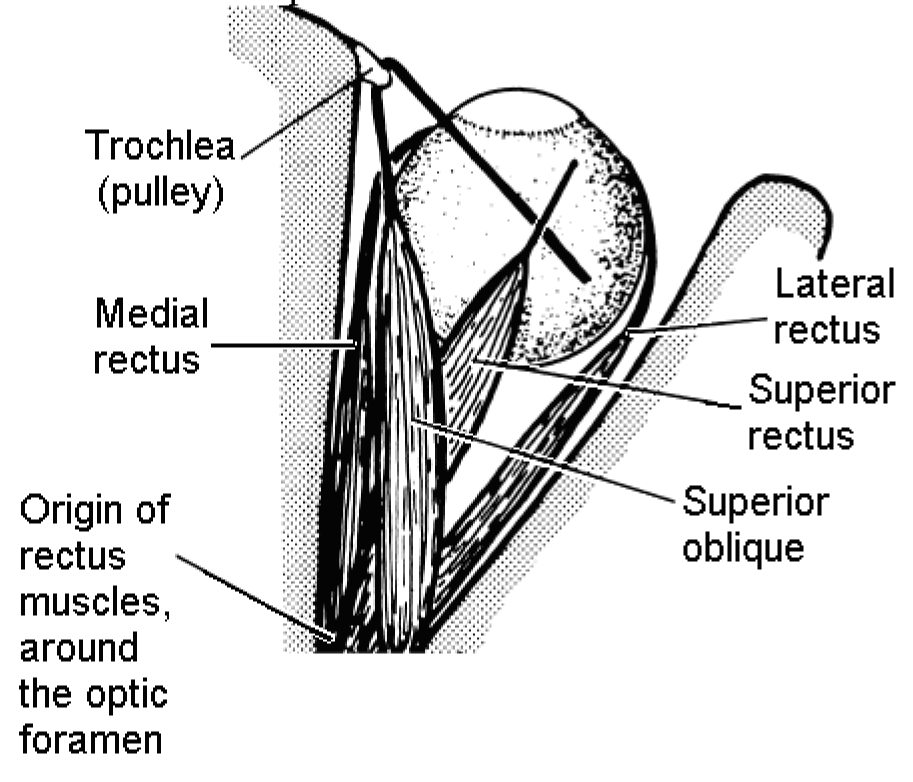
It arises from the lateral portion of the tendinous ring as it bridges the superior orbital fissure.

- The superior oblique muscle:

It is a long and slender muscle that arises from the body of the sphenoid bone above and medial to the optic canal just outside the tendinous ring.

The muscle runs forward between the roof and medial wall of the orbital cavity and gives rise to a rounded tendon.

The tendon then passes through a pulley or trochlea, and emerging from the trochlea, the tendon bends downward, backward, and laterally. It then pierces the fascial sheath of the eyeball and passes inferior to the superior rectus muscle.

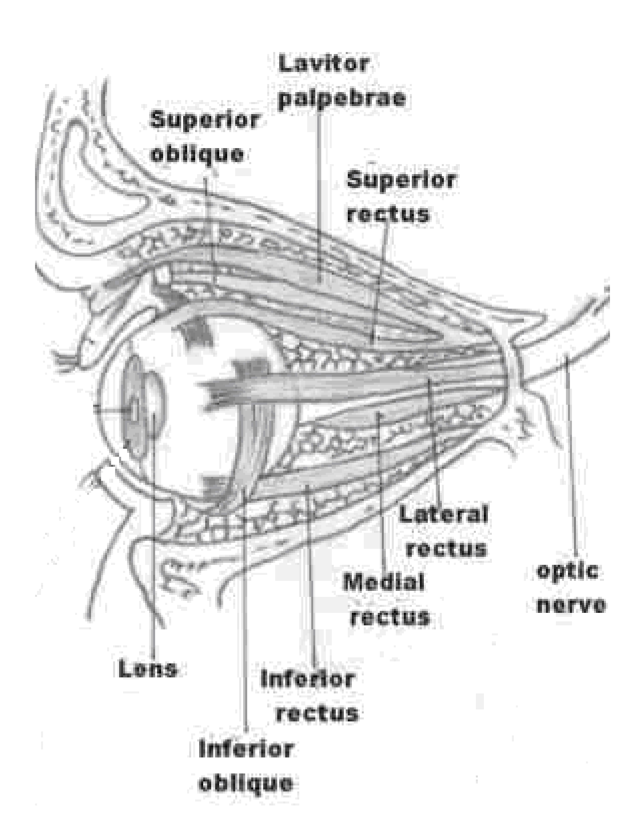


❖ The inferior oblique muscle:

This muscle is the only muscle within the orbit to take origin from the front of the orbit.

It arises from the floor of the orbit just posterior to the orbital margin and just lateral to the nasolacrimal canal.

The muscle passes laterally, posteriorly, and superiorly. It runs inferior to the inferior rectus muscle and reaches the posteriolateral aspect of the eyeball, where it inserts into the sclera under the lateral rectus muscle.



- **Eye movements Terminology:**

1. **Monocular movements(ductions):**

   - Adduction: movement of the eye nasally.
   - Abduction: movement of the eye temporally.
   - Elevation (sursumduction): upward movement of the eye.
   - Depression (deorsumduction): downward movement of the eye.
   - Intorsion (incycloduction): nasal or inward rotation of the eye.
   - Extorsion (excycloduction): temporal or outward rotation of the eye.

2. **Binocular movements(versions):**

- The conjugate binocular eye movements are:

  - Right gaze (dextroversion).
  - Left gaze (levoversion).
  - Elevation (sursumversion).
  - Depression (deorsumversion).
  - Dextrocycloversion: rotation of both eyes to the right.
  - Levocycloversion: rotation of both eyes to the left.

- The disconjugate eye movements are:

- Convergence: movements of both eyes nasally to a given position.
- Divergence: movement of both eyes temporally to a given position.

- ❖ Agonist muscle: the primary muscle that moves an eye in a given direction.

- ❖ Synergist muscle: the muscle in the same eye that helps the agonist muscle to produce certain movement in the same eye.

For example: I.R and S.O muscles give depression in the same eye.

- ❖ Antagonist muscle: the muscle in the same eye that moves the eye in the opposite direction of the agonist muscle.

- ❖ Yoke muscles: two muscles one in each eye which are the prime movers of both eyes to one direction.

Example: when the eyes move to the right gaze the Rt L.R & the Lt. M.R simultaneously contract.

- ❖ Herring law: equal and simultaneous innervation to yoke muscles concerned with the desired direction of gaze.

- ❖ Sherrington's law: for the amount of contraction innervation of agonist muscle there is an equal amount of relaxation innervation of its antagonist

For example: contraction of the Lt L.R muscle will lead to inhibition of contraction of the M.R muscle in the same eye.

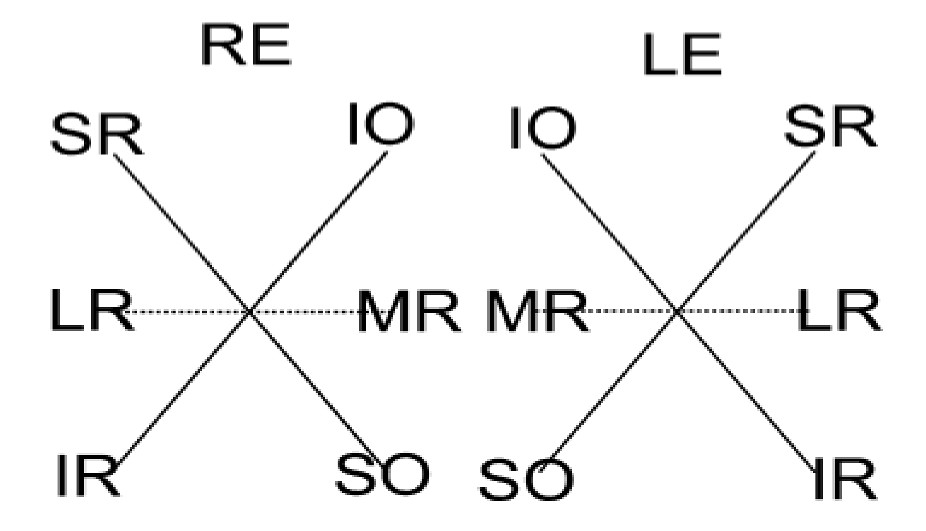
- **Functions of the extraocular muscles:**

This table below shows the functions of the extraocular muscle:

Muscle	Primary action	Secondary action	Tertiary action
Superior rectus	elevation	intorsion	adduction
Inferior rectus	depression	extorsion	adduction
Lateral rectus	abduction	-------	--------
Medial rectus	adduction	--------	---------
Superior oblique	intorsion	depression	abduction
Inferior oblique	extorsion	elevation	abduction

Note: the tertiary action of the rectus muscles is adduction and for obliques muscle is abduction.

Superior muscles are intorters and inferior muscles are extorters.



❖ Specific structure of extraocular muscles:

The basic contractile unit of the muscle fiber is the sarcomere.

The muscle fibers arranged longitudinally, each fiber running most of the length of the muscle.

❖ There are two different types of muscle fibers:

1. A thin slow contracting type: they generate slow or tonic eye movements.
2. A thick fast contracting type: they generate fast eye movements

❖ Muscle innervations:

- Lateral rectus muscle is innervated by the abducent nerve (sixth cranial nerve VI).

- Superior oblique muscle is innervated by the trochlear nerve. (Fourth cranial nerve IV).

- Superior rectus, medial rectus, inferior rectus, and inferior oblique are innervated by the oculomotor nerve (third cranial nerve III).

❖ Blood supply of the extraocular muscles:

The blood supply of the extraocular muscles is via the muscular branches of the ophthalmic artery.

- Lateral muscular branch supplies the lateral rectus, superior rectus, superior oblique, and the levator palpebrae superioris muscle.

- Medial muscular branch (larger) supplies the inferior rectus, medial rectus, and the inferior oblique muscle.

- The muscular branches give rise to seven anterior ciliary arteries accompanying the four rectus muscles, two branches for each rectus muscle, except the lateral rectus muscle has one artery.

- These arteries pass to the episclera and then give blood supply to the sclera, limbus, and conjunctiva.

- The venous drainage is via the superior and inferior orbital veins.

Chapter Six

The Cranial Nerves

The Oculomotor Nerve

It is the third cranial nerve, and it supplies all the extraocular muscles of the orbit except the superior oblique and the lateral rectus, it also supplies the intraocular muscles, the sphincter pupillae, and the ciliary muscle with parasympathetic fibers.

It emerges from the anterior aspect of the midbrain; it perforates the dura mater and comes to lie in the lateral wall of the cavernous sinus above the trochlear nerve.

The oculomotor nerve divides into two branches:

I. Small superior division: it supplies

1. Levator palpebrae superioris.
2. Superior rectus muscle.

II. Large inferior division:

It divides into three branches to supply:

1. Medial rectus muscle.
2. Inferior rectus muscle.
3. Inferior oblique muscle.

Also it contains parasympathetic fibers from Edinger-Westphal nucleus to supply:

1. The sphincter pupillary muscle of the iris.
2. Ciliary muscle.

❖ **Clinical symptoms of a third nerve palsy:**

1. Exotropia, the patient will be unable to move his eye medially.

2. Drooping of the upper eyelid in the same side of the lesion or the palsy of the nerve.

3. Dilation of the pupil in the same side of the lesion or the palsy of the nerve. No reaction to light.

4. Ocular movements affected to varying degrees with limitations in adduction, elevation and depression.

5. Weakness of the inferior rectus, medial rectus, inferior oblique on the same side as the lesion.

6. The patient cannot accommodate.

7. Weakness of the superior rectus of the opposite side, because the nucleus supplies the superior rectus of the contralateral eye.

❖ Oculomotor nerve nuclei:

The oculomotor nerve has two motor nuclei:

1) The main motor nucleus which is located in the anterior part of the gray mater of the midbrain at the level of superior colliculus.

2) The accessory parasympathetic nucleus (Edinger-Westphal nucleus) which is situated posterior to the main oculomotor nucleus.

The Trochlear Nerve

The trochlear nerve (cranial nerve IV) is the fourth cranial nerve, and it is the longest and most slender of the cranial nerves, it supplies the superior oblique muscle in the orbit.

It is the only nerve to leave the posterior surface of the brainstem; emerge from the midbrain and immediately decussates with the nerve of the opposite side, thus it innervates the contralateral superior oblique muscle.

The trochlear nerve passes forward through the middle cranial fossa in the lateral wall of the cavernous sinus and enters the orbit through the superior orbital fissure.

The trochlear nerve is entirely motor and assists in turning the eye downward and laterally.

❖ **Symptoms of trochlear nerve palsy:**

1- Movement of the eye toward the nose (adduction).

2- Turn the eye outward (extorsion).

3. Movement of the eye upward.

3- The patient reports vertical diplopia when looking down gaze.

4- Patients may adopt an abnormal head position to avoid diplopia by depressing the chin, tilting the head and usually turning face to the opposite side.

The nucleus of the trochlear nerve is situated in the anterior part of the gray matter of the midbrain; it lies inferior to the oculomotor nucleus at the level of inferior colliculus.

Abducent Nerve

Abducent nerve (cranial nerve VI) is the sixth cranial nerve which is a small motor nerve that supplies the lateral rectus muscle of the eyeball.

- It emerges from the anterior surface of the brain stem in a groove between the lower border of the pons and the medulla oblongata. It passes forward through the cavernous sinus then it enters the orbit through the superior orbital fissure.

- The abducent nerve is entirely a motor nerve and supplies the lateral rectus muscle and so it is responsible for turning the eye laterally.

- The nucleus situated beneath the floor of the upper part of the fourth ventricle.

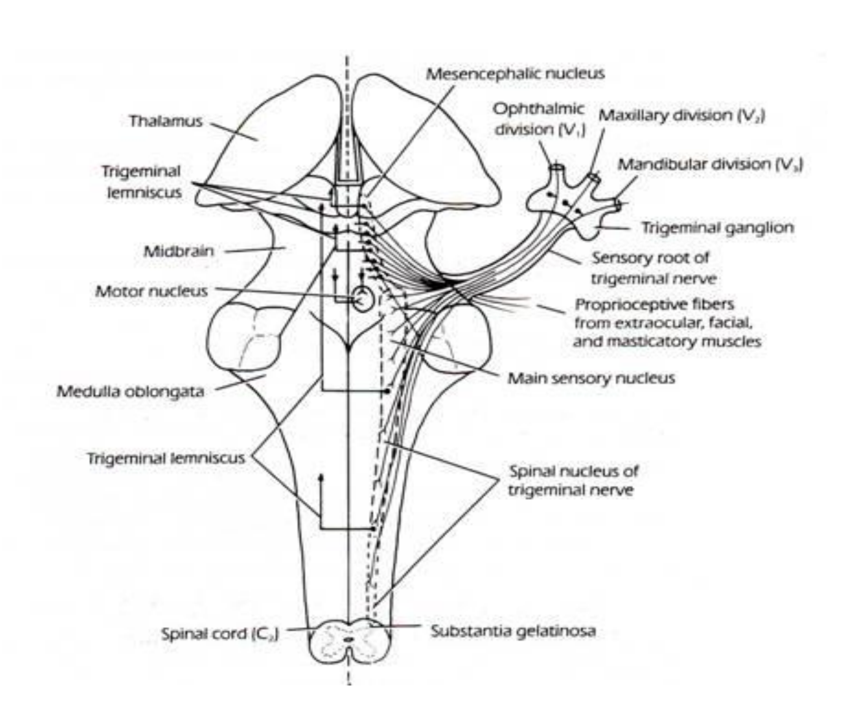
❖ **Symptoms of Abducent nerve palsy:**

1. Defective abduction of the eye due to weakness of the lateral rectus muscle.
2. In the primary position there will be an esotropia.
3. Horizontal diplopia that increase for far.
4. In order to avoid diplopia, the patient adopts a face turn to the opposite side.

The Trigeminal Nerve

The trigeminal nerve is considers as the largest mixed cranial nerve (sensory and motor), the motor nerve innervates the muscles of mastication; the sensory nerve innervates the face, eye, the orbit, and the most of the internal surface of the nasal and oral cavities.

The trigeminal nerve leaves the anterior aspect of the pons, near its upper border as two roots; the small motor root and the large sensory root which expands to form a swelling called the semilunar (trigeminal) ganglion. From this ganglion, the ophthalmic, maxillary and the mandibular branches arise. The smaller motor root passes inferior to the sensory ganglion.



The trigeminal nerve as its name indicates that it is composed of three branches:

1. **Ophthalmic division of trigeminal nerve:**

The ophthalmic nerve (V_1) is the superior and smallest division of the trigeminal nerve. It is entirely sensory.

It emerges from the upper part of the ganglion and passes forward along to the cavernous sinus; it passes between the trochlear nerve and the maxillary division of trigeminal nerve and lateral to the abducent nerve.

It is divided into three branches: lacrimal, frontal, and nasociliary.

I. The lacrimal nerve:

It is the smallest of the three branches of the ophthalmic. It enters the orbit through the superior orbital fissure.

It branches to supply the lacrimal gland, conjunctiva, and the upper eyelid.

II. The frontal nerve:

It is the largest branch of the ophthalmic nerve. It enters the orbit through the superior orbital fissure, and runs between lacrimal and trochlear nerves.

❖ It divides in to two branches:

1. The supratrochlear nerve: it supplies the conjunctiva and skin of the upper eyelid and the skin of the medial part of the forehead.

2. The supraorbital nerve: it supplies the conjunctiva and the medial part of the upper eyelid, the skin of the forehead and the scalp, and the mucous membrane of the frontal air sinus.

III. **The Nasociliary Nerve:**

It enters the orbit through the medial part of the superior orbital fissure between the two divisions of the oculomotor nerve.

The nasociliary nerve ends by passing through the anterior ethmoidal foramen, where it becomes known as the anterior ethmoidal nerve. It supplies the mucous membrane of the anterior ethmoidal air cells.

❖ Branches of the nasociliary nerve:

١. Ramus communicans to the ciliary ganglion (communicating branch):
It contains sensory nerve fibers from the eyeball.

2. The long ciliary nerves:

They are usually two or three in number; they supply the ciliary body, iris and cornea and usually contain sympathetic fibers for the dilator pupillae muscle of the iris.

3. The infratrochlear nerve:

It arises from the nasociliary nerve close to the anterior ethmoidal foramen. It supplies the skin of the eyelids, the conjunctiva,

lacrimal sac, lacrimal caruncle, and the side of the nose above the medial canthus.

4. The posterior ethmoidal nerve:

It leaves the orbit by the posterior ethmoidal foramen and supplies the ethmoidal and sphenoidal sinuses.

2. The maxillary division of trigeminal nerve:

The maxillary nerve (V_2) is intermediate in position and size between the ophthalmic and mandibular divisions of the trigeminal nerve, it is wholly sensory.

The maxillary nerve leaves the trigeminal ganglion between the ophthalmic and mandibular divisions and enters the cavernous sinus. It exits the skull through the foramen rotundum in greater wing of the sphenoid bone to enter the pterygopalatine fossa, and here it branches to posterior superior alveolar nerve and zygomatic nerve then it enters the infraorbital canal as the infraorbital nerve

On reaching the face the nerve divides into branches to supply the lower eyelid, the skin and mucous membrane of the cheek and upper lip.

3- The mandibular nerve :

The mandibular nerve (V_3) is the largest of the three branches of the trigeminal nerve, and is consist of two root: a large, sensory root emanate from the semilunar ganglion then passes the foramen ovale, and a small motor root (the motor part of the trigeminal), which passes beneath the ganglion

Then the motor root unites with the sensory root immediately after emerging from the foramen ovale. Sensory root supply the teeth and gums of the mandible, the skin of the temporal region, the auricular, the lower lip, the lower part of the face, and it also supply the mucous membrane of the anterior two-thirds of the tongue. And motor root supply the muscles of mastication.

- ❖ Trigeminal nerve nuclei:

The nucleus of the trigeminal nerve start at the midbrain to the upper cervical part of the vertebral column until the fourth cervical vertebra, and it consists of four nuclei:

1. principal sensory nucleus.
2. The spinal nucleus.
3. The mesencephalic nucleus.
4. The motor nucleus.

- ❖ **Cilliary ganglion:**

It is a small, flat irregular shaped ganglion, measuring between 1 and 2 mm in diameter. It lies between the optic nerve and the lateral rectus muscle, usually lateral to the ophthalmic artery. It is a peripheral parasympathetic ganglion.

It receives three roots:

1. The parasympathetic root: it derived from the branch of the oculomotor nerve to the inferior oblique, the fibers travelling in the short ciliary nerves to the sphincter pupillae muscle and ciliary muscle.

2. The sympathetic root: it is a branch from the internal carotid plexus; it passes through the ciliary ganglion and exit to

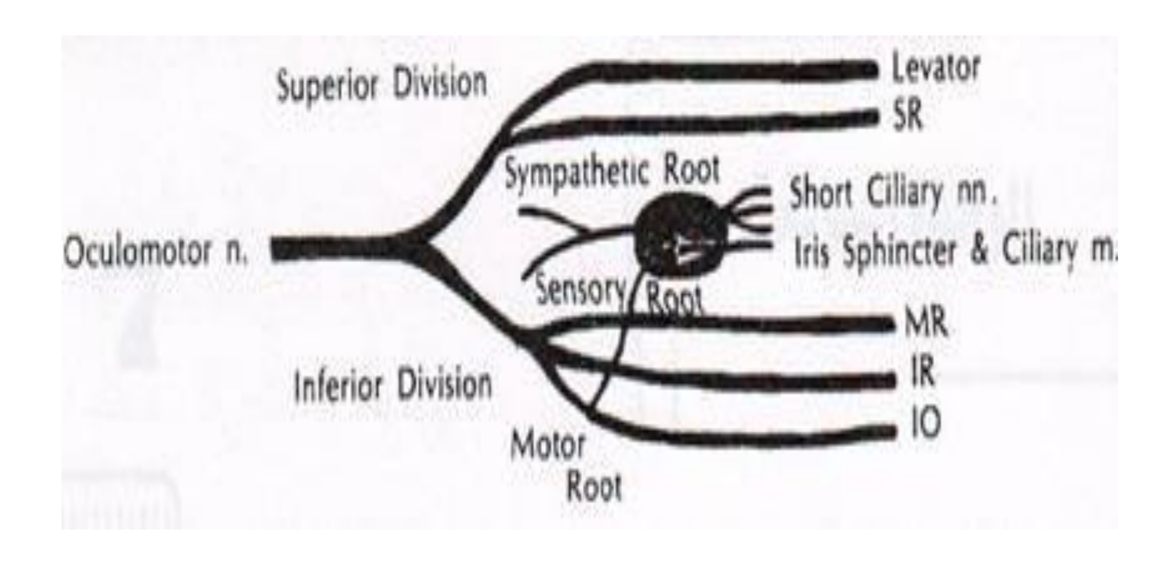
supply the blood vessels of the eyeball and the pupil dilator muscle.

3. The sensory root: it is derived from the nasociliary nerve; it contains sensory fibers from the eyeball which reach the ganglion in short ciliary nerves.

- Branches of ciliary ganglion:

The branches of the ciliary ganglion are eight to ten delicate filaments which emerge in two or three bundles, called short ciliary nerves.

With the ciliary arteries they run forwards above and below the optic nerve which pierce the sclera around the optic nerve. They contain motor (sympathetic and parasympathetic) and sensory fibers. These fibers distributed to the sphincter and ciliary muscles and to choroidal and iridal blood vessels.



The facial Nerve

The facial nerve(cranial nerve VII) is the seventh cranial nerves, it emerges from the anterior surface of the brain between the pons and the medulla; it has motor and sensory roots.

The facial nerve supplies the muscles of facial expression, the auricular muscles, the stapedius, the posterior belly of the digastric and the stylohyoid muscles in the neck.

It also supplies the submandibular and sublingual salivary gland, the lacrimal gland, and the glands of the nose and palate.

It also receives taste fibers from the anterior two-thirds of the tongue, the floor of the mouth, and the palate.

- ❖ Facial nerve nuclei:

The facial nerve has three nuclei:

1- The main motor nucleus
2- The parasympathetic nuclei (superior salivatory and lacrimal nuclei).
3- The sensory nucleus.

Chapter Seven

The Visual Pathway

The visual pathway

The retina, the optic nerve, the optic chiasma, the optic tracts, the lateral geniculate bodies, and the visual cortical areas make up the visual pathway.

- ❖ **Optic Nerve:**

It is the second cranial nerve, and it begins at the lamina cribrosa in the retina, it composed of the ganglion cells axons and it ends at the optic chiasm, its length is approximately 5 cm.

The arachnoid space of the optic nerve is continuous with the arachnoid space of the brain.

- The optic nerve may be divided into four parts:

1. **Intraocular portion**:

The intraocular portion includes the optic disc and that portion of the optic nerve that lies within the sclera.

The optic disc lies about 3 mm nasally to the macula lutea and slightly above the posterior pole of the eyeball.

It measures about 1.5 mm in diameter and has a pale pink color; it is much paler than the surrounding retina.

2. **Orbital portion**:

As the optic nerve traverses the lamina cribrosa, they acquire myelin sheath, which are formed by oligodendrocytes.the presence of the myelin and the oligodendrocytes cause the optic nerve to increase in diameter to 3-4 mm.

The orbital portion of the optic nerve is about 25 mm long.
The optic nerve is surrounded by a dense sheath of dura mater, a middle delicate sheath of arachnoid, and an innermost vascular sheath of pia mater.

3. **Intracanalicular portion:**

The optic canal lies within the lesser wing of the sphenoid bone and is about 5 mm long.

4. **Intracranial portion:**

The optic nerve leaves the canal and passes backward, upward, and medially within the subarachnoid space to reach the optic chiasma.

❖ **Optic chiasma:**

The optic chiasma is situated at the junction of the anterior wall and floor of the third ventricle.

In the chiasma the nerve fibers from the nasal half of each retina (including the nasal half of the macula) cross the midline and enter the optic tract of the opposite side; the nerve fibers from the inferior nasal retina cross at the anterior part of the chiasma, where

as the nerve fibers from the superior nasal retina cross at the posterior part of the chiasma. These fibers are called crossed fibers.

The nerve fibers at the temporal half of the retina pass backward into the optic tract of the same side. These fibers are called uncrossed fibers.

- ❖ **Optic tracts:**

The optic tracts emerge from the posterolateral angles of the optic chiasma as cylindrical bands.

Most of the nerve fibers in the optic tract terminate in the lateral geniculate body and are concerned with visual sensation.

Just before the nerve fibers of the optic tract enter the lateral geniculate body, about 10 percent pass medially to enter the superior colliculus and the pretectal nucleus, these fibers are not concerned with visual sensation, but are involved in visual body reflexes and light reflexes.

- ❖ **Lateral geniculate body:**

It is a small swelling of the thalamus; it received the termination of the optic tract.

It contains six layers of cells; these layers are numbered from 1-6 beginning inferiorly.

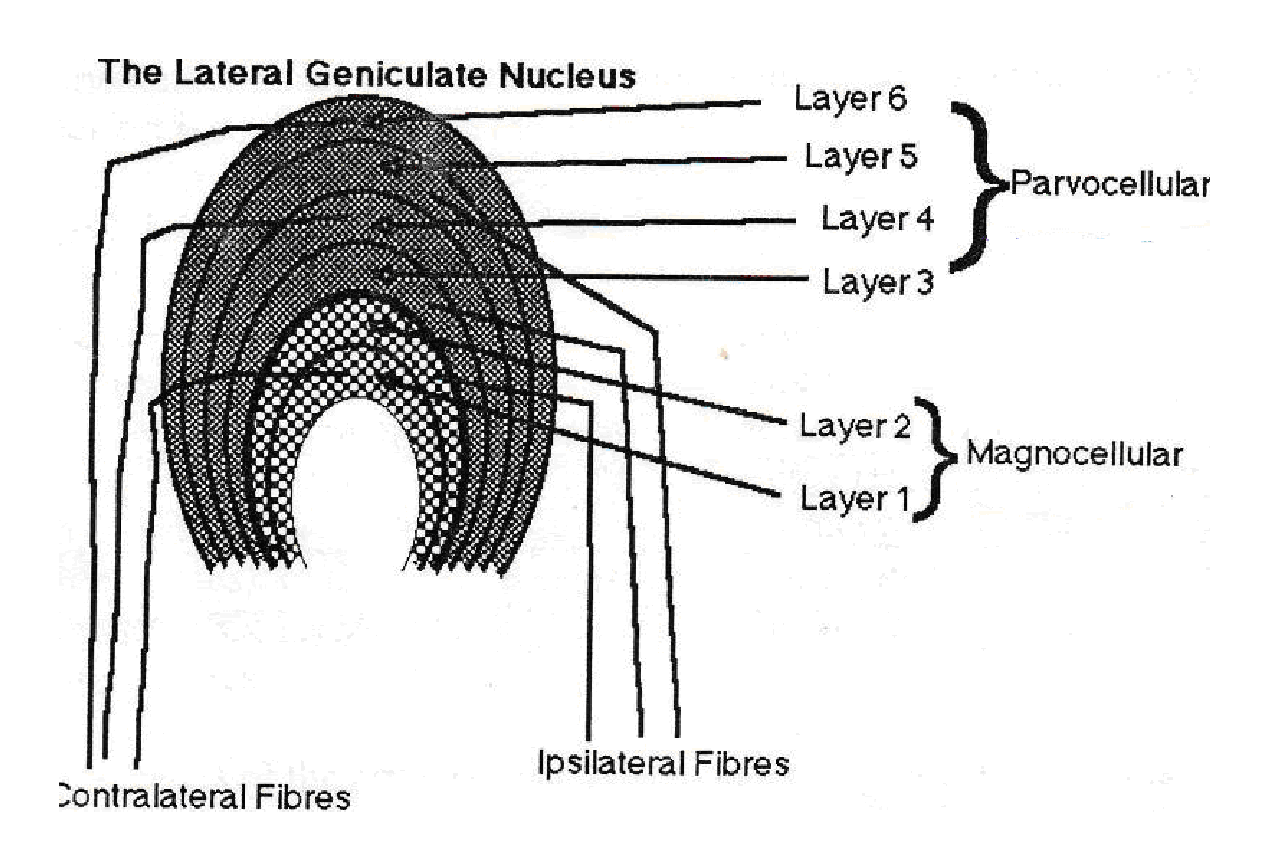
The contralateral eye sends its nerve fibers to layers 1,4 and 6 while the ipsilateral eye sends its nerve fibers to layers 2,3 and 5, so each lateral geniculate body receives visual information from both retinas.

The nerve cells in layers1 and 2 are large and are called the Magnocellular layers.

The layers 3 to6 contain smaller cells and are called Parvocellular layers.

The fibers of the optic nerve which coming from the superior part of the retina connect with nasal part of the lateral geniculate body, but the nerves that coming from the inferior part of the retina connect with the temporal part of the lateral geniculate body.

Each LGN contains about 1 million neurons, all of which project to the ipsilateral occipital cortex as the optic radiations.



❖ Optic radiation:

It is formed of nerve fibers that originate from the nerve cells in the laminae of the lateral geniculate bodies.

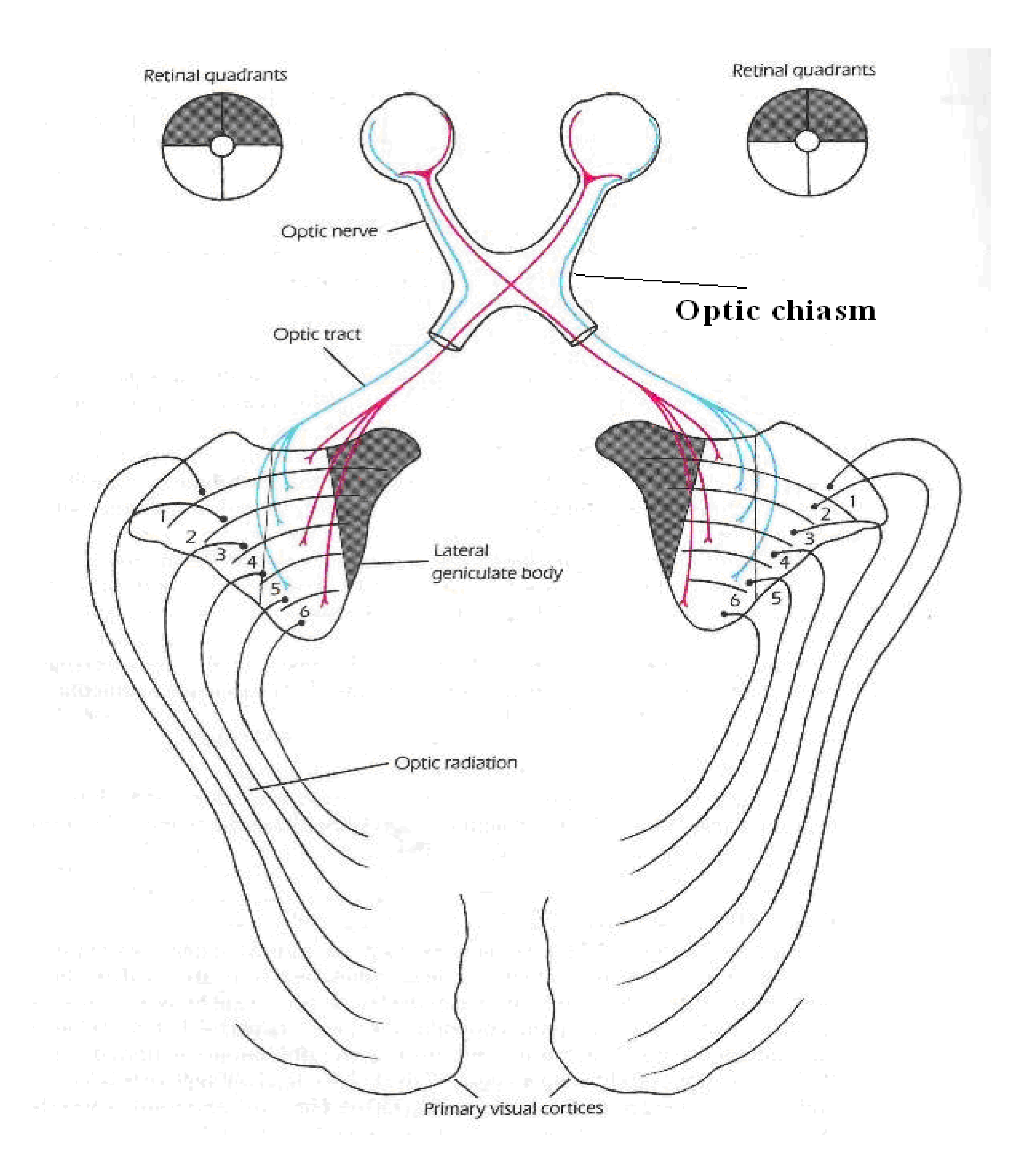
The superior optic radiation parts represent the superior part of the retina in the occipital cortex of the brain and the inferior optic radiation part represents the inferior part of the retina in the occipital cortex of the brain.

❖ Visual cortical areas:

The visual cortex may be divided into the primary visual cortical area (Brodmann area 17) and the secondary visual area (Brodmann's areas 18 and 19).

The secondary visual areas surround the primary visual area and its function is to relate the visual information received by the primary visual area to past visual experience and so enabling the individual to recognize and appreciate what he or she is seeing.

The visual cortex receives fibers from the temporal half of the ipsilateral retina and the nasal half of the contralateral retina. The right half of the field of vision, therefore, is represented in the visual cortex of the left cerebral hemisphere and vice versa.



Blood supply to the visual pathway:

- The optic disc: branches of the central retinal artery and branches of short ciliary arteries.

- Intraocular portion: from branches of short posterior ciliary arteries.

- Orbital portion: branches of ophthalmic artery and branches from central retinal artery.
- Intracanalicular portion: branches from the ophthalmic artery.
- Intracranial portion: ophthalmic artery and branches from internal carotid artery.
- The optic chiasma: anterior cerebral artery, anterior and posterior communicating arteries, and the internal carotid artery.
- The optic tract: anterior choroidal artery, posterior communicating artery, and from middle cerebral artery.
- The lateral geniculate body: branches from middle and posterior cerebral arteries and lateral choroidal artery.
- The optic radiation: the anterior portion is supplied by the anterior choroidal branch of the internal carotid artery, and the posterior portion by the middle and posterior cerebral arteries.
- The visual cortex: posterior and middle cerebral artery.

Chapter Eight

The Orbital Blood Vessels

The Orbital Blood Vessels

The eye and the orbital contents receive their main arterial supply from the ophthalmic artery. The venous blood of the orbit is drained by the superior and inferior ophthalmic veins.

❖ Arteries of the orbit:

I- Ophthalmic Artery:

The ophthalmic artery is a branch of the internal carotid artery. It passes forward through the optic canal below and lateral to the optic nerve.

Branches of the ophthalmic artery:

1- *Central retinal artery:*
The central retinal artery divides into superior, inferior, nasal, and temporal branches. The four arteries supply a quadrant of the retina.

The central retinal artery and its branches distributed to the inner layers of the retina, the outer layer, which includes the photoreceptors, is avascular and nourished by fluid diffusing from the choroidal blood vessels.

2- *Lacrimal artery:*
The lacrimal artery supplies the lacrimal gland and sends terminal branches to the eyelids and conjunctiva.

3- *Muscular branches*:
The arteries which supply the rectus muscles give origin to the anterior ciliary arteries.

4- *Ciliary arteries:*
There are three groups of ciliary arteries: the long posterior, the short posterior, and the anterior.

The long posterior ciliary arteries, usually two in number, they anastomose with the anterior ciliary arteries to form the *major arterial circle of the iris* which supplies the iris and the choroid.

The short posterior ciliary arteries are seven in number and supply the choroid.

It enters the retina at the lateral border of the optic nerve and supplies an area of the retina between the optic disc and the macula.

The anterior ciliary arteries originate from the muscular branches of the ophthalmic artery to the four rectus muscles. There are two anterior ciliary arteries associated with each rectus muscle, with the exception of the lateral rectus muscle, which is provided only one anterior ciliary artery. These arteries supply the sclera and the conjunctiva.

5- *Supraorbital artery:*
The supraorbital artery supplies the levator palpebrae superioris, the frontal sinus, the upper eyelid, and the skin of the forehead and the scalp.

6- *Posterior ethmoidal artery:*
The artery supplies the posterior ethmoidal air sinuses.

7- *Anterior ethmoidal artery:*
The anterior ethmoidal artery is larger than the posterior ethmoidal artery.
The artery supplies the anterior and middle ethmoidal air cells and the frontal air sinus.

8- Meningeal artery:
It supplies the meninges of the middle cranial fossa.

9- Medial palpebral arteries:
Their branches supply the eyelids and conjunctiva.

10- Supratrochlear arteries:
It supplies the skin of the forehead and conjunctiva.

11- Dorsal nasal artery:
It gives branches to the lacrimal sac.

II- Infraorbital Artery:

It arises from the maxillary artery, besides supplying the maxillary air sinus; the infraorbital artery gives off orbital branches to the inferior rectus and inferior oblique muscles and the lacrimal sac.

- **Veins of the Orbit:**

The orbit is drained by the superior and inferior ophthalmic veins, which in turn drain directly into the cavernous sinus. The central retinal vein usually drains directly into the cavernous sinus or into the superior ophthalmic vein.

1- Superior Ophthalmic Vein:

This is the larger of the two ophthalmic veins

2- Inferior Ophthalmic Vein.

3- Central Vein of the Retina:
The vein drains directly into the cavernous sinus or enters the superior ophthalmic vein. The central vein always communicates with the superior ophthalmic vein.

4- Infraorbital Vein.

Chapter Nine

Embryology of the Eye

Embryology of the Eye

Four types of embryological tissues participate in the formation of the human eye. These are neural ectoderm, surface ectoderm, mesoderm and neural crest cells.

1) Neural ectoderm:

This forms the walls of the optic vesicle, the optic cup which differentiate into the sensory retina and the retinal pigment epithelium, the iris epithelium and muscles (sphincter and dilator), the ciliary epithelium and the neural portion of the optic nerve.

2) Surface ectoderm:

From this tissue are derived the lens, corneal epithelium, conjunctiva, eyelid epithelium and glands, and the lacrimal gland.

3) Mesoderm:

From this tissue are derived the extraocular muscles and the endothelial lining of all orbital and ocular blood vessels.

4) Neural crest cells:

They also called as secondary mesenchyme, in the eye they develop into the keratocytes, corneal endothelium, trabecular meshwork, iris and choroidal stroma, ciliary muscle, sclera, fibroblasts and the meninges of the optic nerve.

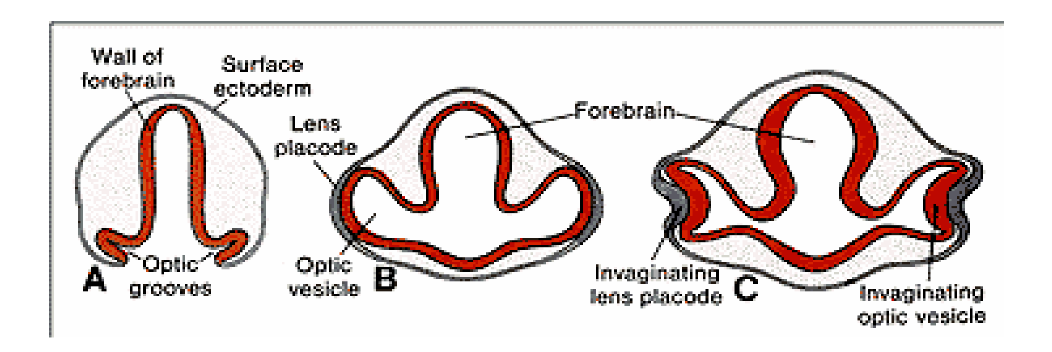
❖ Development of the optic vesicle and lens:

The rudimentary eye ball develops as a diverticulum from the lateral aspect of forebrain. It grows out laterally and the end becomes slightly dilated to form the **optic vesicle** (around day 22 of gestation), while the proximal portion becomes constricted to form optic stalk.

As this is occurring, the surface ectoderm thickens to form a **lens placode** which invaginated to become **lens vesicle** (around 27 day of gestation).

Once the formation of the lens placode has begun, the optic vesicle begins to invaginate by the lens vesicle to form the double-layered optic cup.

The inferior edge of optic cup is deficient, so forming a shallow groove, this groove is called optic or choroidal fissure and allow the hyaloid artery to reach the developing lens. This choroidal fissure closes by the seventh week, failure in closing the fissure results in coloboma formation.



❖ Development of the retina:

It is developed from the optic cup, the retina may be divided into two developmental layers:

1. The pigmented layer:
It is formed from the outer layer of the optic cup.

2. The neural layer:
It is developed from the inner portion of the optic cup

By 15 weeks, most of the cells and layers of the retina are present, although differentiation continues with the further development of the bipolar and horizontal cells.

❖ Development of the macula and fovea centralis:

At 22 weeks the macular area develops as a localized increase of superimposed nuclei in the ganglion cell layer

During the seventh month, there is a peripheral displacement of the ganglion calls leaving a small depression called the **fovea centralis.**

Just after birth the ganglion cell layer is no more than one layer in the fovea, and the human fovea reaches maturity between 15 and 45 months after birth.

❖ Development of the optic nerve:

It develops from the optic stalk, and it is formed by the axons of the ganglion cell layer.

The axons begin to develop their myelin sheath just before birth, but the process is not completed until some time later.

❖ **Development of the outer layer:**

- The Sclera:

During the fourth month collagenous fibers extend posteriorly and by the fifth month the sclera is well-differentiated around the whole globe.

- The Cornea:

After five weeks of gestation the earliest corneal manifestation is noted, the corneal epithelium begins to form.
By fourth to fifth months all the corneal layers are present with the exception of the Bowman’s membrane which appears later in the developing fetus at the fifth month.

❖ **Development of the middle layer:**

-The Choroid:

All the layers of the choroid can be recognized by the fifth month.

Pigment is present in the choroid around 7-8 months, vessels will form between 2-4 months.

- The ciliary body:

The first folding occurs in the pigmented epithelium in week 11, followed by the non- pigmented epithelium. Zonule fibers have been identified in week 12.

- The iris and pupil:

The peripheral part of the iris is composed of blood vessels and mesenchyme, while the central, pupillary region eventually disappears leaving the pupil.
At the end of the third month, the vascular iris stroma begins to form.
The earliest sign of muscle development in the human iris is at 11 to 12 weeks.

❖ **Development of the vitreous humor**:

The vitreous humor consists of primary or hyaloid vitreous, secondary vitreous, and tertiary vitreous.

1- The primary vitreous which consists of hyaloid artery and its branches formed by the fifth week, and by the seventh week the hyaloid artery reaches the lens.

2- Secondary vitreous has been developing between the retina and the primary vitreous, and it becomes complete by the third month.

3- Tertiary vitreous begins to form at vitreous base around the end of 3rd month of gestation.

❖ **Development of the eyelids:**

The eyelids grow together and by the third month they fuse and adhere together.

The lids remain fused until about the fifth month when they start to separate, and by the seventh month separation is completed.

❖ **Development of the Extraocular muscles:**

The muscles innervated by the oculomotor nerve (medial rectus, superior rectus, inferior rectus, inferior oblique) are apparent by 26th days.

The lateral rectus muscle appears on the 27th days, and the superior oblique muscle by the 29th days.

The levator palpebrae superioris forms from the superior rectus muscle and is complete during the fourth month.

References

1- Clinical anatomy of the eye, second edition ,Richard S. Snell, Michael A. Lemp

٢- Pediatric Eye Care , edited by Simon Barnard and David Edgar.

٣. Clinical Neuroanatomy for medical students, Richard S. Snell, Fifth edition.

٤. Gray's Anatomy, Thirty –eight edition.

5. Concise Text of Neuroscience, Robert e. Kingsley, second edition.